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WELDING RESEARCH

29, PARK CRESCENT, LONDON, W.1

ASSOCIATION NOTES

This Issue

On the following pages of this final issue of *Welding Research* we have included a review of the work of the Association since its inception in 1946 until April 1953. On the reverse side of this page appears a "family tree" showing the various research committees which have taken part in the growth of the organization, followed by an introduction by the Director of Research and then a report on the work of each individual committee.

The report is taken from documents prepared by each of the four Main Committees of the B.W.R.A. at the request of the Research Board.

Membership

Since the list in the October, 1952, issue of the journal, and up to and including September, 1953, the following companies have joined the British Welding Research Association:

Members

British Engine, Boiler & Electricity Insurance Co. Ltd.
Gibbons Brothers Ltd.
Surrey Tool Development Co. Ltd.
Aluminium Laboratories Ltd.
Aluminium Corporation Ltd.
Birmid Industries Ltd.
High Duty Alloys Ltd.
Richard Thomas & Baldwins Ltd.
The Aluminium Wire & Cable Co. Ltd.
Almin Ltd.
Alar Ltd.
Bristol Aeroplane Co. (Weston) Ltd.
British Light Steel Pressings Ltd.
Fulmer Research Institute Ltd.
Priestman Brothers Ltd.
Leyland Motors Ltd.
Sir Robert McAlpine & Sons Ltd.
James Mitchell & Son (Greenock) Ltd.
North British Locomotive Co. Ltd.
Rustproof Metal Window Co. Ltd.
Round Oak Steel Works Ltd.
Pye Telecommunications Ltd.
Johnson & Phillips Ltd.
British Federal Welder & Machine Co. Ltd.
Canadian Welding Bureau.
The Pyrene Co. Ltd.
Thermal Welding Products Ltd.

Associate Members

Wilkie & Paul Ltd.
Hardy Martin (Constructions) Ltd.
Saunders & Taylor Ltd.
Gresham Transformers Ltd.
Sterling Cable Company Ltd.

RESEARCH COMMITTEES OF B.W.R.A. DURING PERIOD 1946-53

COUNCIL

FINANCE COMMITTEE

RESEARCH BOARD

RFM
Main Ferrous Metals (Metallurgical) Committee

- FM.1—Alloy steel metallurgy.
- FM.2—Weldability tests.*
- FM.3—Weld metal constitution.
- FM.4—Arc characteristics.*
- FM.5—Welding slags.*
- FM.6—Practical problems.*
- FM.8—High-strength structural steels.
- FM.9—Welded gas mains.
- FM.10—Oxygen cutting.
- C.R.S.—Handbook for stainless steel welding.*

RL
Main Light Alloys Committee

- LM.1—Fusion welding. *Revised* 1952.—Arc welding.
- LM.2—Strong aluminium alloys.*
- LM.3—Fusion welding Mg base alloys. *Revised* 1952—Welding Mg base alloys.
- LM.4—Recrystallisation welding.*
- LM.6—Testing welds.*
- LM.7—Self-adjusting- and controlled-arc processes.
- LM.8—High-strength alloys.

RFE
Main Engineering Committee

- FE.1—Frame structures.
- FE.2—Structural connections.*
- FE.6—Radiography of pressure vessels.*
- FE.7—Design of machinery construction.*
- FE.8—Fatigue in structures.
- FE.10—Pipe lines.*
- FE.12—Stresses in pressure vessels.
- FE.13—Codes for building structures.*
- FE.14—Heat treatment.*
- FE.15—Specs. for electrodes.*
- FE.16—Pipe connections.
- FE.17—Faults in arc welds.*
- FE.18—Non-destructive testing.
- FE.19—Residual stresses.
- FE.20—Welded chains.
- FE.21—Fatigue of ship structures (in abeyance)
- FE.22—Fatigue of pipe lines.
- FE.23—Fatigue of thin-gauge constructions.

RR
Main Resistance Welding Committee

- FR.3—Projection welding steel.
- FR.4—Flash welding steel (in abeyance).
- FR.5—Instrumentation.
- FR.6—Spot welding steel.
- FR.7—Fundamentals.
- LR—Spot welding light alloys.

* These Committees became inoperative during the period under review, their work having been completed or transferred to other Committees.

The Formative Years

A Review of Progress from March, 1946, to April, 1953

FOREWORD by DR. H. G. TAYLOR, D.Sc.(ENG.), D.I.C., M.I.E.E., F.Inst.P.

A review of work of the British Welding Research Association appears on the following pages under the heading "The Formative Years"—a title which is really descriptive of the whole field of welding research in Great Britain during the years under review. During this period there has been a steady increase of activity both by the Association and by industry. As welding becomes an ever more powerful assembly tool, an understanding of the fundamentals of the process becomes increasingly important. This has been well appreciated by industry, by the Department of Scientific and Industrial Research and by the Service Departments who have steadily enlarged their direct contract work with the Association.

The first attempt to organise welding research on any scale in this country was started in 1936 by the Institute of Welding with the setting up of a Research Committee, afterwards known as the Welding Research Council. The major portion of the work was carried out on a co-operative basis with industry, the Universities and a number of existing research organisations. With the limited sum of money available this method of working was satisfactory and a considerable amount of research of an exploratory nature was carried out, but as problems became more clearly defined there was seen to be a need for a more sustained effort by a group of research workers operating under a unified control. The first step in this direction was taken in March, 1946, with the incorporation of the B.W.R.A. under the scheme of the Department of Scientific and Industrial Research for Grant Aided Research Organisations. Some idea of the growth of the Association's work can be gained from the fact that its income has been almost trebled since 1946.

Soon after the inception of the Association the Journal *Welding Research* was started—originally as a Research Supplement to the *Transactions of the Institute of Welding*—and over one hundred reports have been published in it to date. However, with the ever-increasing volume of research work there has now become an urgent need for more space for published work and, as already announced, after this issue many of the reports of the Association will be appearing monthly in the new *British Welding Journal*.

The reports published by the Association in *Welding Research* and in other technical journals represent about one-tenth of the number of confidential reports that are circulated to the controlling committees in order that they can observe the progress of the research work, and it can be readily seen that a considerable amount of information on welding research has been accumulated. It is therefore most useful to complete the seven years during which *Welding Research* has been published with a final issue devoted to a review of the work of the Association during this period.

The review is written in terms of the individual work done for the research committees which advise on all aspects of B.W.R.A. research. Within the space available it has not been possible to acknowledge individually the contributions of the many representatives from the industry of this country who have devoted so much of their valuable time to this honorary work, but the progress of the work reported on these pages speaks for them. Finally, in paying tribute to the loyal committee members, one must also add a word of praise for the members of the staff, both past and present, who, during these formative years, have helped to make the Association a success.

H. G. T.

The Formative Years

COMMITTEE ORGANISATION

The Research Committees fall into four groups, each supervised by a Main Committee as follows:—

Main Ferrous Metals (Metallurgical) Committee (RFM).
Main Light Alloys Committee (RL).
Main Engineering Committee (RFE).
Main Resistance Welding Committee (RR).

These Committees report to the Research Board and brief summaries of the work done under their guidance by the various research committees are appended.

Miscellaneous Researches

The Research Board or one of the main committees, noted above, has directly supervised the following investigations for which there were no individual committees.

Brittle Fracture

Following the occurrence of catastrophic failures due to brittle fracture in structures previously thought to be immune from this trouble, the Association has initiated an investigation of the mechanics of brittle fracture. This investigation has enabled two significant contributions to be made to the understanding of the fracture conditions. The first of these is recognition of the important part played by strain hardening in initiating the fractures from the roots of notches. This process was hitherto ascribed more to triaxiality or shock. In general, it has now been shown that strain hardening at the roots of notches, sufficient for brittle fracture initiation, is only produced at general yield of the structure, but may take place at lower loads, where the notches are near welds, because of the pronounced plastic flow which accompanies the heating and cooling in all fusion welding operations.

The other contribution has been the development of a simple method for accurate measurement of the energy absorbed in creating unit surface area of crack, by recording the temperature wave released. This surface energy has been found to have stable minimum values for given materials and temperatures. In view of the high speeds of propagation of brittle fractures, the absorption of surface energy is linked closely with the availability of stored elastic energy in the structure at the instant preceding failure. Thus, the essential role of surface energy lies with this balance, so that the minimum size of a given notch or crack may be determined for propagation of the fracture to take place at a given general elastic stress level. In practice, this should facilitate the determination of weld fault size tolerances (in conjunction with non-destructive testing methods) for safety from brittle fracture, and the choice of dimensions for such devices as crack arrestors, in cases where the use of fully notch-tough steel is precluded.

Published Work

WELLS, A. A.—"The Mechanics of Notch Brittle Fracture," *Welding Research*, **7** (2), 1953.

Measurement of surface energy of a propagating brittle fracture. Photographic recording of temperature wave.

Nitrogen-Arc Welding of Copper

Brief researches in the Association's metallurgical laboratories have established the feasibility of using nitrogen as a neutral shrouding gas for the welding of copper and its alloys. Carbon electrodes were used in place of tungsten electrodes, as the latter tend to be attacked to some extent at high temperatures. A report has been issued to members, together with brief résumés of the work carried out at the British Oxygen Co. Ltd., and at I.C.I. Metals on the same subject.

Reports to Members

RB/85/53 WINTERTON, K.—Nitrogen-Arc Welding of Copper.
RB/98/53 Nitrogen-Shielded Arc Welding of Deoxidised Copper.
RB/100/53 CRESSWELL, R. A., of the British Oxygen Co. Ltd.—Nitrogen as a Shielding Gas for the Welding of Copper and Brass.

Pressure Welding

After 1947 the work of the LM.2 Committee on Recrystallisation Welding was ceded to the Main RL Committee. Since then, extra-mural research on this subject has been supported by the Association and a number of reports have been issued.

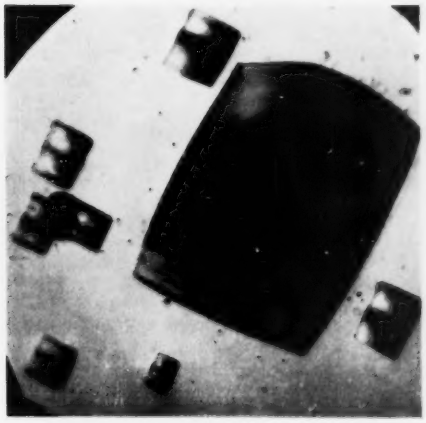
The main object of this work was the establishment of the principles involved in pressure welding, and in particular the correlation between weldability of various metals at room temperature and the physical properties of the oxide film. It has been shown that a relationship exists between the minimum deformation for welding and the ratio of hardness of oxide to hardness of metal, e.g. the minimum ratio for super-purity aluminium is 40 per cent. and the oxide/metal hardness ratio is 3·1; for mild steel the values are 84 per cent. and 1·9. Welding of iron or copper to aluminium can be done more easily than either aluminium to aluminium or copper to copper. This has been attributed to the fact that the breakdown of the oxide film on the aluminium is facilitated when the second metal is much harder. The presence of absorbed gas film also has an important effect when oxide films are absent, i.e. on gold and in certain circumstances on silver.

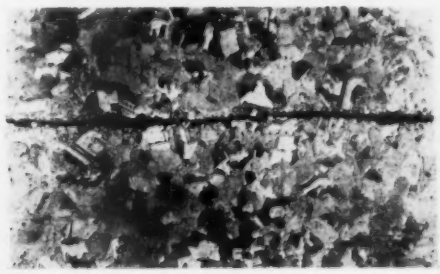
Some work has also been carried out on the effect of crystal orientation on the transinterfacial grain growth in pressure welding by using a single crystal of aluminium. The results showed that grain growth occurred preferentially with the (110) to (110) and (111) to (111) planes.

Tests on the welding of de-oxidised copper in hydrogen, to prevent the formation of oxide, confirmed that a good weld could be obtained at temperatures within the range 250-450 deg. C. with deformations of about 15-20 per cent. At room temperature, welds could not be obtained with deformations of less than 80 per cent., due to the nature of the cuprous oxide film which could only be reduced at temperatures of about 250 deg. C. (See also LM.4 Committee).

Reports of Members

RB/70/50 TYLECOTE, R. F.—Progress Report on the Fundamentals of Pressure Welding.
RL/30/52 TYLECOTE, R. F.—Second Progress Report on Pressure Welding.
RL/33/52 TYLECOTE, R. F.—Third Progress Report on Pressure Welding.





(Above) *Pressure welding deoxidised copper at* 500 *deg. C., with* 15 *per cent. deformation after reduction of oxide in hydrogen (semi-taper section).* ×120

(Left) *Orientation of single crystal of high-purity aluminium. Photo-micrograph showing* 110 *plane.* ×1200

NOTE. Reference code for B.W.R.A. reports gives:— Committee for which report was prepared / sequence number of committee report / year issued to members, e.g. RB/70/50.

Welding of Ferrous Metals

FM.1 COMMITTEE—Physical Metallurgy of Alloy Steel Welding

Terms of Reference—"To investigate the influence of physical changes in the parent and weld metals on the behaviour of the joints during and after welding."

The work of this committee has been carried out at Birmingham University and since October, 1947, has been mainly controlled by B.I.S.R.A. with financial support from B.W.R.A.

Investigations on low-alloy steels showed that overheating was due to the precipitation of manganese sulphide on the grain boundaries; this was discovered by the direct examination of boundary surfaces in cleavage fractures. Burning was found to be associated with a phosphide network along the austenite grain boundaries, and the precipitation of manganese sulphide on the cubic planes of the austenite was found to be responsible for cleavage fracture in certain steels.

Local stresses in martensite in hardened nickel steels were measured using X-ray diffraction methods. These stresses were found to form a pattern, the distance between adjacent maxima and minima being extremely small. The average value of these stresses was found to be about 40-60 per cent. of the tensile strength of the steel, the value of the stresses increasing rapidly with carbon content. An important method using a Geiger counter spectrometer was devised for the investigation of plasticity and workhardening described above.

The application of a new theoretical method using strain tensor analysis which has been used to determine the habit plane of martensite will be of wider use for problems in the crystallography of transformation.

It has been shown that bainite forms by a shear mechanism, subsequent coherent growth being restricted by carbon diffusion and removal, either by diffusion into adjacent austenite or by precipitation.

Reports to Members

MG/A/259/48 *Prepared by B.I.S.R.A.* Grain Boundary Precipitation of Inclusions Produced by High Temperature Heating of Steel.

MG/A/164/50 *Prepared by B.I.S.R.A.* WHEELER, J. A., KONDIC, V., and KO, T.—Effect of Initial Heating Temperature on the Mechanical Properties of Ni-Cr-Mo Steels.

Published Work

WHEELER, J. A., and JAWSON, M. A.—"The Breadths of X-ray Diffraction Lines from Martensite," *Journal Iron and Steel Institute*, **157**, 1947, p. 161.

JAWSON, M. A., and WHEELER, J. A.—"Atomic Displacements in the Austenite-Martensite Transformation," *Acta Crystallographica*, **1**, 1948, p. 216.

WHEELER, J. A.—"The Stress System Causing Hard-Zone Cracking in Welded Alloy Steels," *Institute of Metals Symposium on Internal Stresses*, 1947.

HALL, W. H., ARNDT, U. W., and SMITH, R. A.—"A Geiger Counter Spectrometer for the Measurement of Debye-Scherrer Line Shapes," *Proc. Phys. Soc.*, **62A**, 1949, p. 631.

KO, T., and HANSON, D.—"Grain Boundary Phenomena in Severely Heated Steel," *Journal Iron and Steel Institute*, **164**, 1950, p. 51.

WHEELER, J. A., KONDIC, V., and KO, T.—"Effect of Initial Heating Temperature on the Mechanical Properties of Ni-Cr-Mo Steels," *Journal Iron and Steel Institute*, **167**, 1951, p. 301.

KO, T., and COTTRELL, S. A.—"The Formation of Bainite," *Journal Iron and Steel Institute*, **172**, 1952, p. 307.

FM.2 COMMITTEE—Weldability Tests for Specification Purposes

Terms of Reference—"To study weldability tests with the object of recommending (if possible) one or more standard tests for specification purposes in connection with the metallic-arc welding of steel."

The committee was disbanded with its work completed early in 1951.

Several tests for hard-zone cracking were examined and, after a number of earlier methods had been rejected, the Controlled Thermal Severity (C.T.S.) test was devised; this was further modified for small steel test specimens.

This test is used in industry and by Government and Service Departments, and is now being incorporated in a British Standard for electrodes for use with medium-high-tensile structural steel.

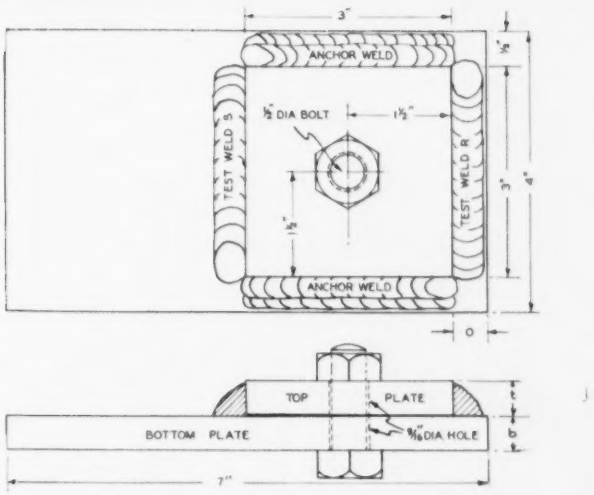


Diagram showing the dimensions of the standard C.T.S. weldability test assembly.

If only a limited amount of material is available, a smaller modified form of the assembly can be used.

Reports to Members

FM.2/38A/51 Weldability test for Employment in Specifications for the Arc Welding of High-Tensile Structural Steels.

Published Work

"C.T.S. Weldability Test for High-Tensile Structural Steels Welded by the Metal-Arc Process," *Welding Research*, **6** (5), October, 1952, p. 89*r*.

FM.3 COMMITTEE—Constitution of Weld Metal

Terms of Reference—"To investigate the constitution and properties of weld metal."

The main programme of work, initiated in 1946, *has been carried out in the metallurgical laboratories of the Association and is still in progress. Some additional work, originally undertaken by the National Physical Laboratory on the analysis of non-metallic inclusions, was transferred to the Northampton Polytechnic in* 1950.

A hot-cracking test, now known as the double-fillet test, has been developed as a result of the research work. This has already proved of some value in the investigation of hot cracking and has been of use to electrode manufacturers in the development of electrodes.

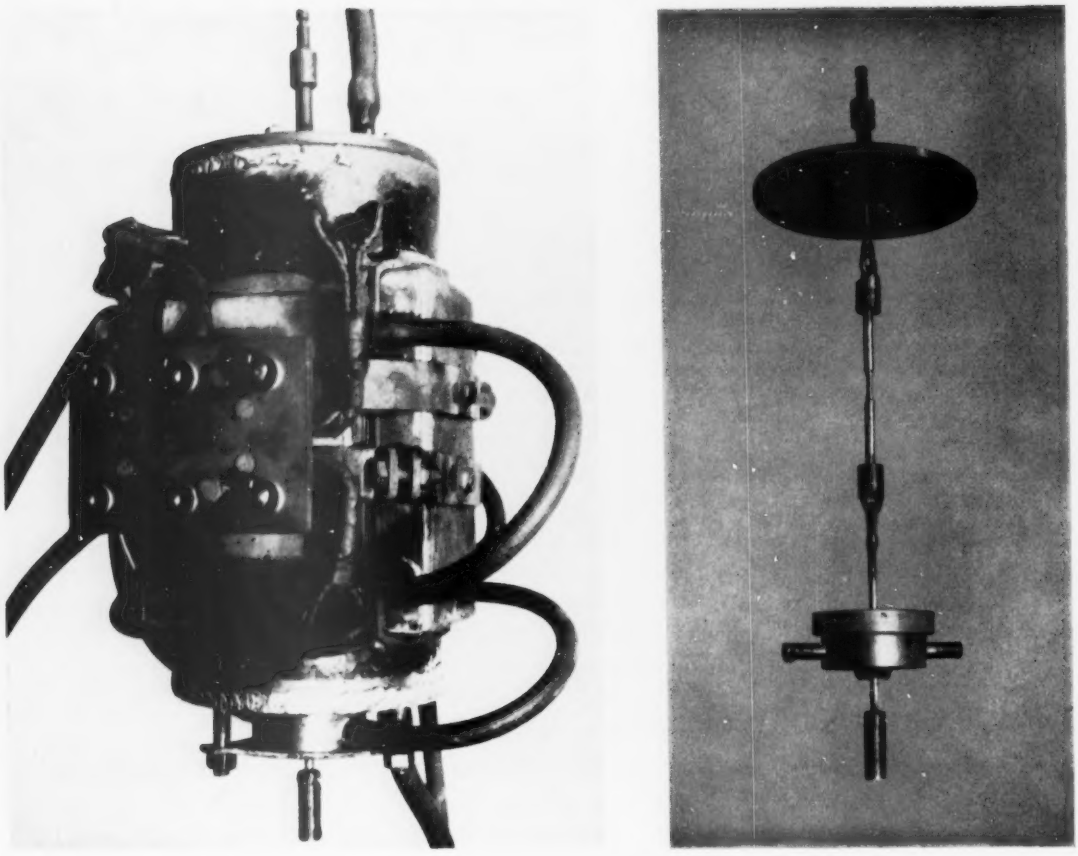
Trials have been made in the Association's laboratories and in those of a number of co-operating firms to see whether it can be made useful as a workshop test. Interest in the test has been shown also in America (Battelle) and in Holland.

High temperature mechanical properties of weld metal in the range 700-1400 deg. C. have been determined for various electrodes. A brittle region has been discovered in the temperature range 900-1100 deg. C., probably associated with the cast structure, although the prime cause of this phenomenon has not yet been discovered. It is possible that there may be several types of hot cracking, one of which may be associated with this brittle range.

Some of the work indicated that cracking can occur at very high temperatures (1300-1500 deg. C.) but no correlation has been found with ductility in the mechanical tests.

Some interesting evidence has been obtained to show that hydrogen is a contributory factor in causing hot cracking, and it has also been demonstrated that the oxygen and nitrogen in the atmosphere do not play a part in this phenomenon. Examinations of mild steel weld metal subject to hot cracking showed a very fine grain-boundary precipitate. This was confirmed with the electron microscope, and it was shown that the precipitate was heavier with those weld metals most liable to give hot cracking.

In connection with this work, some preliminary experiments have been made to measure the forces exerted by a contracting weld, using a dynamometer in conjunction with a special jig, and it has been found that the forces involved are rather small at the time when hot cracking occurs.



Furnace for measurement of ductility at high temperatures, with (right) *the test piece and holding mechanism.*

Haloes in mild steel weld metal have been investigated, and it has been shown that they do not begin to form until a specimen has been plastically deformed to 10-15 per cent. Experiments to determine the influence of rate of strain have shown that haloes are not produced on impact testing or explosive tensile loading. Evidence is available that hydrogen plays an important part in the formation of haloes, but the exact mechanism is still unknown.

The Committee is guiding a programme of work on the constitution of non-metallic inclusions in arc-welded deposits, this being originally undertaken in connection with the work on haloes, though it was always understood that the results obtained would be of great use in a more general way by contributing to an explanation of the behaviour and properties of welds. The work was initiated at N.P.L. and later carried on at Northampton Polytechnic where a new micro-X-ray method is being developed. A number of the more recent types of electrodes are being examined and the effect of arc length on the types of inclusions present is also receiving some attention.

Reports to Members

FM.3/42/49 BALL, J. G., and WINTERTON, K.—Progress Report on High Temperature Properties of Weld Metal (Addendum to Doc. FM.3/37).

FM.3/43/49 BALL, J. G., WINTERTON, K., and HINDS, E. G. P.—An Investigation of Factors Affecting the Severity and Consistency of the T-Test for Hot Cracking of Weld Metal.

FM.3/55/50 WINTERTON, K.—Turning Contraction of a Fillet Weld in Relation to the Temperature of Hot Cracking.

FM.3/57/50 SLOMAN, H. A.—Determination of the Percentage and Constitution of Oxide Inclusions in Three Samples of Mild Steel Weld Metal.

FM.3/59/50 WINTERTON, K.—Examination of Weld Metal Structures under the Electron Microscope.

Note 1951 HINDS, E. G. P.—Note on Development of a New Double-Fillet Test for Hot Cracking in Weld Metal.

Published Work

BALL, J. G., and WINTERTON, K.—"Tensile Properties of Mild Steel Weld Metal at High Temperatures," *Welding Research*, **4** (6), Dec., 1950.

HINDS, E. G. P.—"A New Double-Fillet Test for Hot Cracking," *Welding Research*, **6** (1), Feb., 1952.

FM.4 COMMITTEE—Electro-Physics of the Arc

This Committee was originally formed with the following terms of reference:—"To determine the influence of electro-physical conditions of the arc on the mechanism of deposition and the properties of deposited weld metal."

A considerable amount of practical work was done in the Laboratories of the Electrical Research Association, including work using a high-speed photographic method on globule formation in the iron arc.

In the autumn of 1947 the control of the research was transferred to a committee of the Electrical Research Association.

Reports to Members

FM.4/7A/46 ORTON, L. H.—Electro-Physics of the Welding Arc—Trends of Recent Research.

FM.4/9/47 ORTON, L. H., and NEEDHAM, J. C.—The Electro-Physics of the Welding Arc—Initial Investigations.

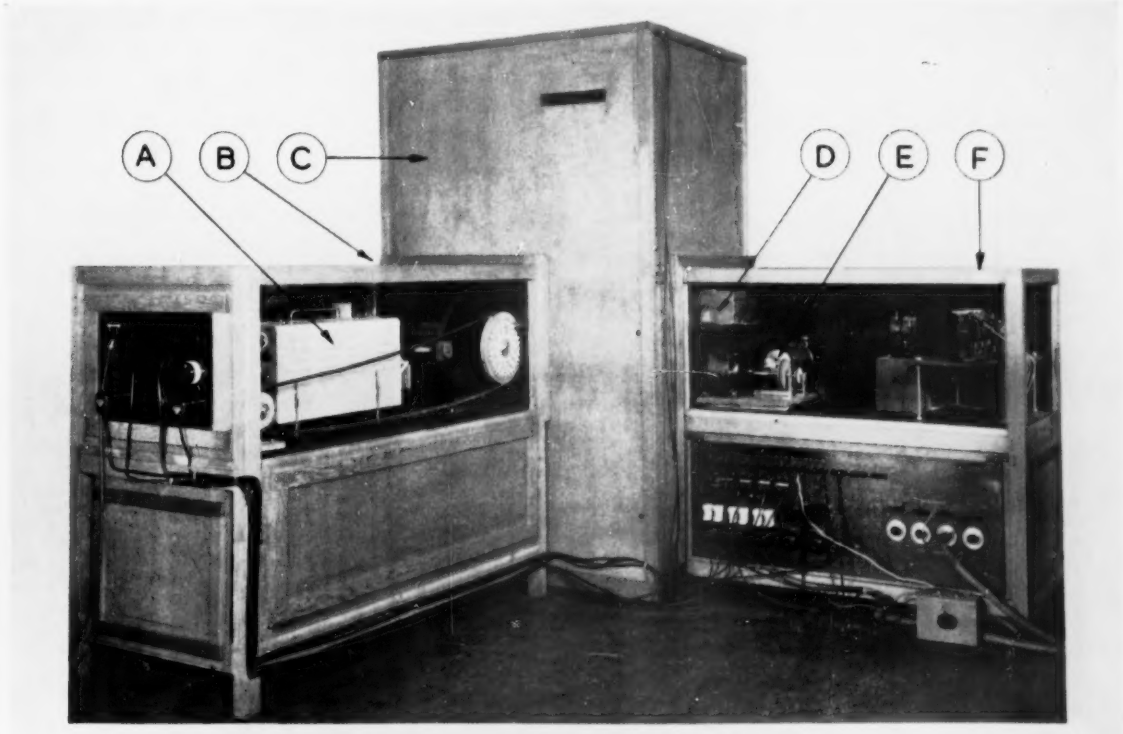
FM.4/11/47 ORTON, L. H., and NEEDHAM, J. C.—Some Characteristics of the Iron Arc Related to Welding, with Particular Reference to Arc Voltage.

Z/T 72/47 *Prepared by E.R.A.* ORTON, L. H., and NEEDHAM, J. C.—Short Time Phenomena in the Iron Welding Arc: The Detailed Nature of the Arc Voltage and its Significance.

Z/T 79/49 *Prepared by E.R.A.* ORTON, L. H., and NEEDHAM, J. C.—Micro-Second Phenomena in the Steel Welding Arc.

Published Work

ORTON, L. H., and NEEDHAM, J. C.—"Short Time Phenomena in the Iron Welding Arc, Metal Bridging and Short Circuiting of the Arc," *Welding Research*, **3** (1), Feb., 1949.



Recording unit for iron arc research.

FM.5 COMMITTEE—Viscosity of Welding Slags

Terms of Reference—"To develop a standard instrument for measuring the viscosity of welding slags, and to investigate the relationship between the viscosity and composition of these slags."

The Committee was disbanded in 1948, *having brought the work to completion with a final report on the subject.*

A logarithmic decrement viscometer was developed and constructional details were published. A satisfactory correlation was shown to exist between the length of flow in a simple Herty-type apparatus and the true viscosity of a slag. This greatly facilitated the determination of the approximate viscosity of a welding slag.

Measurements were made of the viscosity of various welding slags, mostly of the rutile type; the figures were in general lower than those for blast furnace slags.

The effect on viscosity of the various constituents of welding slags were investigated, and an empirical formula was suggested which enabled viscosity to be calculated from the SiO_2 and Al_2O_3 contents of a slag.

These results provided background information useful in the design of electrode coatings and indicated how far one constituent could be replaced by another. The results also permitted comparison between different types of electrodes.

Reports to Members

FM.5/20/51 GLEDHILL, P. K.—Final Report on Investigations into the Viscosity of Welding Slags.

Published Work

GLEDHILL, P. K.—"An Apparatus for the Determination of the Viscosity of Welding Slags," Handbook of the Symposium on Metallurgy of Steel Welding, Nov., 1945, *B.W.R.A.*, 1947, pp. 88, 94.

FM.6 COMMITTEE—Investigation of Practical Problems

The terms of reference of this Committee were: "To investigate practical metallurgical problems on the arc welding of steel."

Among other problems, the committee considered brittle fracture in mild steel and the hot cracking of weld metal. The committee was disbanded in 1947 *and its investigations into the high-temperature ductility of weld metal were transferred to the control of the FM.3 Committee.*

FM.8 COMMITTEE—Development of Higher Strength Weldable Structural Steels

The terms of reference of this Committee are: "To extend present knowledge of the influence of the various alloying elements on weld hardening and the tendency to crack of alloy steels when welded under specific welding conditions, with the ultimate object of recommending for commercial development steels of the following classes:—

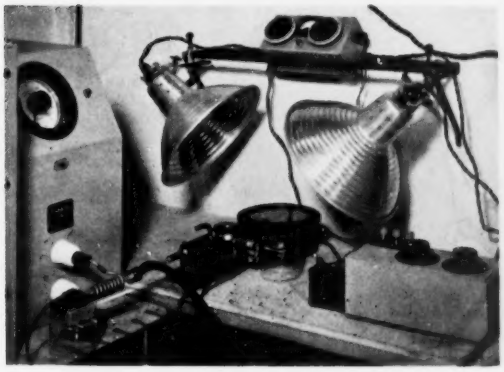
(*a*) *Having* 0.2 *per cent. proof stress of* 25 *tons per sq.in.*
(*b*) *Having* 0.2 *per cent. proof stress of* 30 *tons per sq.in.*
(*c*) *Having* 0.2 *per cent. proof stress greater than* 30 *tons per sq.in.*

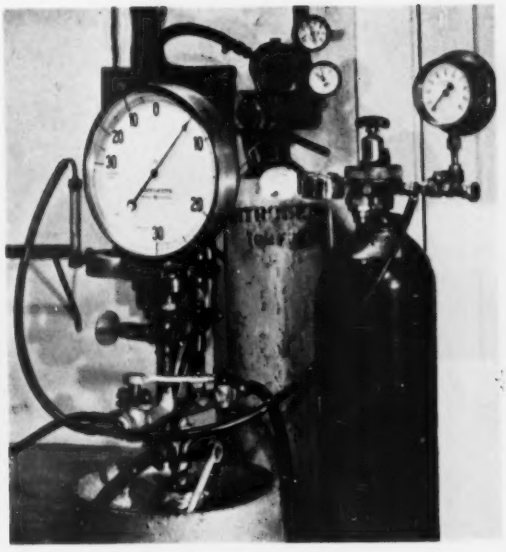
It was further agreed that the following points should be kept in mind during the investigation:—

(*a*) *The possibility that multiple-alloy steels may produce tougher martensite than steel containing only a single alloying element.*
(*b*) *The weldability of a steel may be improved by the use of electrodes with low potential hydrogen content.*
(*c*) *The ratio of yield strength to ultimate strength may have an effect on the service behaviour of a steel."*

Considerable progress has been made in this important field of research since the formation of the Association in 1946, *the work being greatly expedited in* 1948 *when a contract was received from the Ministry of Supply.*

Rapid-action dilatometric apparatus for simulating the conditions which occur adjacent to arc welds.





A series of low-alloy steels of widely varying composition was examined for weldability (resistance to hard-zone cracking) and mechanical properties. Further tests were made on two selected steels made in the form of two-ton casts. In this form the steels were found to have good mechanical strength (0·5 per cent. proof stress of 23-31 tons per sq.in. depending on thickness) and were completely weldable with rutile-coated electrodes. The effect of slight variations of composition on these two steels was examined, and it was shown that carbon had an over-riding influence on both yield strength and weldability.

Investigations were made for the Ministry of Supply on the effect of substituting vanadium for molybdenum in these steels. For two steel compositions, molybdenum can be replaced by half the quantity of vanadium, retaining good weldability and mechanical properties. Moreover, the vanadium steels exhibit a good 0·02 per cent. proof stress in the normalised condition, only obtained in the corresponding molybdenum steels after tempering.

Various tests, suitable for examining liability to hard-zone cracking, were examined for rate of cooling and restraint, and as a result, basic data were provided which made the Controlled Thermal Severity (C.T.S.) test possible. (See also FM.2 Committee.)

The problem of hard-zone cracking has been largely elucidated in terms of hydrogen content, steel composition and the effect of rate of cooling on transformation characteristics. In addition it has been shown that external restraint, previously thought to have an important influence, is not necessary for the initiation of hard-zone cracking. In particular, the effect of rate of cooling in the region of 300 deg. C. has been shown to be critical with respect to the initiation of hard-zone cracking in arc-welded low-alloy steels. This relationship between cracking and rate of cooling was established using weldability tests and also standard types of structural joint.

The assessment of weldability of alloy steels from the point of view of hard-zone cracking is now possible in terms of the properties of the material, measured by means of a physical and mechanical testing schedule. For this purpose, dilatation specimens and tensile specimens have been subjected to a thermal cycle imitating that obtaining in the heat-affected zone of the plate metal.

Dilatation tests of this kind have shown that a relationship exists between the incidence of hard-zone cracking and the temperature for completion of austenite transformation during cooling. For welding rates it has been convenient to plot the results in the form of continuous-cooling time/temperature/transformation curves rather than in the form of the more conventional "S" curves. It has been found that hydrogen depresses the temperature of the austenite-martensite transformation. In a similar way, using mechanical test specimens subjected to the thermal treatment simulating the conditions in the hardened zone of a weld, it has been found that hydrogen has a deleterious effect on the mechanical properties, particularly the static tensile strength of a specimen. This may account for the harmful effect of hydrogen in relation to hard-zone cracking.

Reports to Members

FM.8/49A/50 BALL, J. G., and COTTRELL, C. L. M.—The Weldability and Mechanical Properties of a Series of Experimental Low-Alloy Structural Steels.

FM.8/55/50 COTTRELL, C. L. M.—First Progress Report on the Weldability of Low-Alloy Steel Castings.

FM.8/63/51 Examination of the Possibility of Developing a Weldable High-Tensile Steel by Means of Using 18 lb. Experimental High-Frequency Melts.

(*see over page*)

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Various forms of cracking in the heat-affected zone of a weld in a low-alloy steel. The fundamental reasons for the occurrence of this type of cracking have been investigated by this committee.

Reports to Members (*continued*)

FM.8/70/51 COTTRELL, C. L. M., and BALL, J. G.—Investigations into the Weldability and Mechanical Properties of Colvilles "Ducol W.24" Steel.

FM.8/75/52 COTTRELL, C. L. M., and LANE, P. H. R.—Correlation of Weldability Tests with Structural Joints. Part I: Investigations with Tests of the Restrained Fillet Type.

FM.8/76/51 COTTRELL, C. L. M., JACKSON, M. D., and WHITMAN, J. G.—Control of Cracking in the Metal-Arc Welding of High-Tensile Structural Steels.

FM.8/78/52 COTTRELL, C. L. M., and JACKSON, M. D.—Correlation of Weldability Tests with Structural Joints. Part II: Investigations with Unrestrained Fillet Tests and Structural Joints.

FM.8/81/52 COTTRELL, C. L. M., JACKSON, M. D., and PURCHAS, J. G.—Correlation of Weldability Tests with Structural Joints, Part III: Investigations with the Controlled Thermal Severity Test.

FM.8/83/53 COTTRELL, C. L. M.—Austenite Transformation Characteristics in Relation to Hard-Zone Cracking in Low-Alloy Steel. Part I: Rapid Dilatation Tests on a Series of Experimental Mn-Ni-Cr-Mo Steels as a Means of Assessing Weldability.

Published Work

"Developing Weldable High-Tensile Steel from 18-lb. H.F. Melts," *Welding Research*, **5** (3), June, 1951.

COTTRELL, C. L. M., JACKSON, M. D., and WHITMAN, J. G.—"Control of Cracking in Arc Welding High-Tensile Structural Steels," *Welding Research*, **5** (4), Aug., 1951.

BALL, J. G., and COTTRELL, C. L. M.—"The Weldability and Mechanical Properties of a Series of Low-Alloy Steels," *Journal of Iron and Steel Institute*, **169**, Dec., 1951.

COTTRELL, C. L. M., and LANE, P. H. R.—"Correlation of Weldability Tests with Structural Joints, Part I: Investigations with Tests of the Restrained Fillet Type," *Welding Research*, **6** (1), Feb., 1952.

COTTRELL, C. L. M., and JACKSON, M. D.—"Correlation of Weldability Tests with Structural Joints. Part II: Investigations with Unrestrained Fillet Tests and Structural Joints," *Welding Research*, **6** (2), April, 1952.

COTTRELL, C. L. M., JACKSON, M. D., and PURCHAS, J. G.—"Correlation of Weldability Tests with Structural Joints. Part III: Investigations with the Controlled Thermal Severity Test," *Welding Research*, **6** (3), June, 1952.

COTTRELL, C. L. M.—"Delayed Brittle Fracture of Alloy Steels at Low Stress Levels," *Nature*, **170** (4338), 1952, Dec., p. 1079.

FM.9 COMMITTEE—Cracking in Welded Gas Mains

The terms of reference of this committee are:—"To establish the causes and to attempt to establish a procedure to overcome stress-corrosion cracking in welded gas mains."

The committee decided that the cracking was probably of a type which could be avoided by stress relieving of the complete assembly. The use of stress-relieving as recommended by the committee has been found to be justified, based on experience at industrial installations over the past few years.

The recommendation of this committee that a stress-relieving treatment (450-500 deg. C.) be given to all weldments after fabrication has overcome the immediate problem of the cracking.

A laboratory method of testing the susceptibility of steels to the form of stress corrosion encountered in gas mains has been found to correlate reasonably well with practice. Some progress has been made towards the isolation of the active constituents involved and the other factors affecting this type of cracking.

Work has recently been started on a survey of the possible corrosive agents involved. A range of H_2S/ammonia solutions is being examined, the technique being to examine the grain boundaries for signs of attack.

An approach has been made to the Gas Council, who have agreed to ascertain at which plants trouble has been encountered. It is intended to survey the conditions under which the cracking occurs in practice; the results will be subjected to statistical analysis.

Reports to Members

FM.9/45/51 Investigations into the Stress-Corrosion Cracking in Welded Gas Mains. *Prepared by* KASTELL, L. W.

Published Work

PEARSON, C. E., and PARKINS, R. N.—"Stress-Corrosion Cracking in Welded Steel Structures," *Welding Research*, **3** (6), Dec., 1949.

"Report on Investigations into the Stress-Corrosion Cracking in Welded Gas Mains," *Inst. of Gas Engrs.*, No. 398, 1951.

FM.10 COMMITTEE—Oxygen Cutting

This Committee was formed in 1951 *with the following terms of reference:—"To study the fundamental aspects of oxygen cutting, primarily as a method of preparing plate for welding, with a view to finding out whether any improvements can be made in the economy of the process or in the quality of the result."*

The work on the study of the combustion rate of steel during oxygen cutting has now been completed, and further work, on gas flow conditions, is in progress.

A thermodynamic analysis of the process has been made, and it has been shown that the combustion rate for commercial materials is governed by the rate of physical diffusion of gas molecules to the plate surface.

Combustion rates have also been found to depend upon the Reynold's number of the oxygen stream, as with such other diverse processes as fluid friction, and condensation. In the experiments, as with the theory, it has been shown that 1 per cent. of carbon in the steel has approximately the same suppressing effect on the combustion rate as 5 per cent. of impurities in the oxygen, although it has been established that there is nothing to be gained by the use of super-purity oxygen. It has also been found that there is a limiting carbon content, just as there is a limiting oxygen impurity, at which combustion in oxygen is completely stopped. Finally, the aerodynamic condition of the gas stream leaving the nozzle affects the width of cut as well as the combustion rate.

These factors, when quantitatively determined, are all of importance in establishing the economic conditions for plate edge preparation, heavy cutting and hot billet cropping.

C.R.S. COMMITTEE—Preparation of a book on the Welding of Corrosion- and Heat-Resisting Steels

This Committee was set up in 1948 and appointed an editing panel in 1951 to complete the work. The text was completed late in 1952 and the book was published in January, 1953.

Published Work

"The Welding of Austenitic Corrosion- and Heat-Resisting Steels," *B.W.R.A.*, January, 1953.

Welding of Light Alloys

In 1947 there were only two active committees—the LM.1 and LM.3; but in February, 1952, the committee organisation was revised and four committees were formed.

In general, each committee has its own research programme, but the programmes are co-ordinated and include one or more of three broad aspects—investigations on arc characteristics, thermal effects and weld metal composition.

LM.1 COMMITTEE (to Feb. 1952)—Fusion Welding of Aluminium Alloys

The terms of reference of this committee were:—"To investigate the fusion welding of aluminium alloys with particular reference in the first instance to the arc welding of thick materials, and to alloys of intermediate strength, including the binary aluminium-magnesium-silicon type alloys."

The programme of work undertaken by the committee dealt exclusively with investigations into the welding of materials of medium strength, namely, the aluminium-5 per cent. magnesium alloy (N6) and the heat-treatable aluminium-1 per cent. magnesium-1 per cent. silicon alloy (H10). The work was divided into three broad categories according to the welding process employed.

Metal Arc.—The low joint efficiencies which had been encountered in metal-arc welds in aluminium-5 per cent. magnesium plate of thick section, using existing commercial electrodes, were shown to be due to a number of factors.

(*a*) Traces of the alkali metal sodium introduced into the weld metal by constituents in the electrode coating.

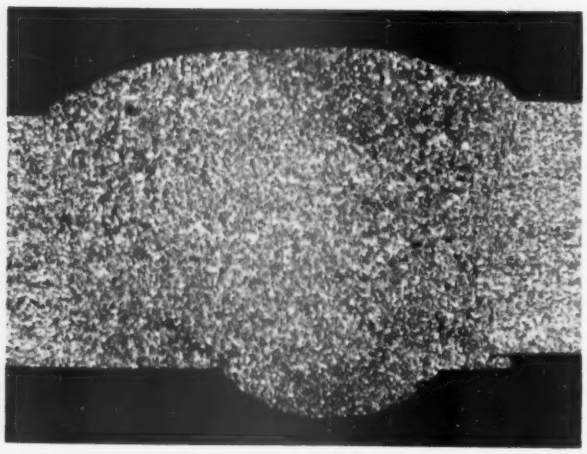
(*b*) Gross and intergranular porosity originating from a number of sources including moisture in the electrode coating and high intrinsic gas content of parent plate and core wire.

(*c*) Loss of magnesium from the electrode material during transfer through the arc.

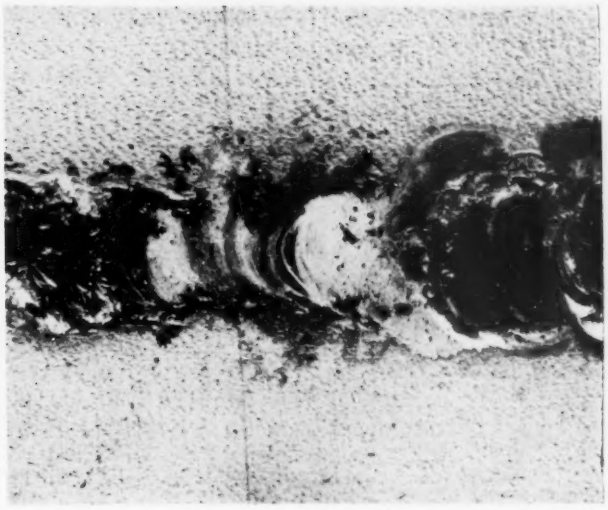
(*d*) Excessive columnar crystallisation in the weld metal.

Using aluminium-7 per cent. magnesium core wire with titanium grain refinement and a coating of sodium-free flux applied by hot dipping, it was shown that joint efficiencies could be raised from under 50 per cent. to about 80 per cent. for welds in parent plate of low hydrogen content. No further work on the development of a suitable electrode has been undertaken by B.W.R.A.

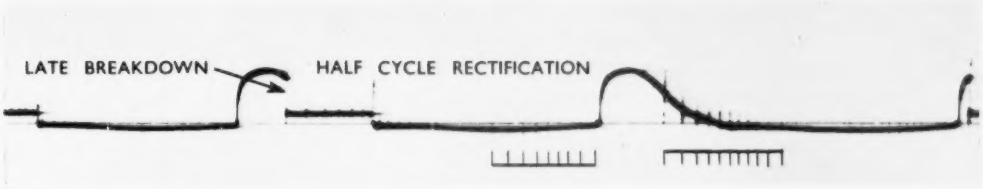
Argon-Arc.—The initial phases of the work were concerned with investigations into the suitability of the process as a method of welding thick plate of the medium strength alloys. Techniques were developed for producing butt welds in various thicknesses of plate, and, provided parent materials and filler rod of low gas content were used, satisfactory joints with high mechanical properties were obtained. Difficulties experienced in welding plate exceeding $\frac{3}{8}$ in. thickness with existing commercial equipment were overcome by constructing a torch of 600 amps. capacity, which is fully water cooled, and enables welds to be made in 1 in. thick plate with a minimum of passes.



Single-pass metal-arc weld in $\frac{1}{2}$ in. thick N.6 plate, using an electrode of similar material containing 0·5 per cent. titanium to prevent columnar crystal growth and elongated porosity.



Incorrect phasing of H.F. injector. Late breakdown of gap giving half-cycle rectification and an oxide covered weld bead.



Special attention was given to the electrical characteristics of the A.C. aluminium-tungsten arc particularly from the arc re-ignition aspect. This latter work was carried out in collaboration with the Electrical Research Association.

The salient features of these investigations were as follows:—

(*a*) Where h.f. spark injection is used as an auxiliary means of arc re-ignition, the input to the h.f. unit should be correctly phased, relative to the welding power source, for satisfactory arc maintenance.

(*b*) From determinations of the minimum open-circuit voltages required for arc maintenance, it was established that the use of h.f. spark injection permits a reduction of about 60 volts, while the insertion of a large series capacitor allows an additional 15 volts reduction.

(*c*) This data led to the development of the Surge Injector unit which permits satisfactory arc maintenance at open circuit voltages below 50 V, r.m.s., and in addition, is free from the radio interference associated with h.f. spark oscillators.

Self-adjusting Arc.—Work on this process was commenced in 1949 with the construction of an experimental welding unit to facilitate the examination of the process as a method of welding the medium-strength alloys. With this equipment it was shown that:—

(*a*) The process could readily achieve all-positional welding in material exceeding $\frac{1}{8}$ in. thickness.

(*b*) The extent of the heat-affected zone was appreciably less than that produced by other processes.

(*c*) Porosity was generally encountered, the extent and distribution being influenced by a number of factors, including surface condition and gas content of electrode wire, arc length, welding technique and rate of solidification of the weld pool.

(*d*) With welds of reasonable soundness, high mechanical properties were obtained.

(*e*) Operating the process above 350 amps. produced deposits exhibiting a severely "puckered" surface, and means of eliminating this are being investigated.

(*f*) Using a sufficiently high heat input, the process could be used to produce cuts of satisfactory appearance in plate up to $\frac{1}{2}$ in. thick.

A detailed study of the electrical characteristics of the self-adjusting arc has been commenced in collaboration with the Electrical Research Association. The original B.W.R.A. equipment is being used in these investigations and a second unit is now available for other work. This equipment is of a light-weight design and is arranged so that it may readily be mounted and carried on the operator's back. This feature is of advantage where structural welding is involved. In addition, the Association has an American "Aircomatic" Mark III equipment on loan from the Ministry of Supply.

REVISED LM.1 COMMITTEE (Feb. 1952)—Metal-Arc and Argon-Arc Welding of Medium-Strength Aluminium Alloys

*The terms of reference of the Committee are:—"To investigate the welding of aluminium alloys other than the HP.*15 *(AW.*15 *and AW.*16 *types) with the ultimate object of producing technique memoranda."*

Investigations by this Committee are at present confined to the metal-arc welding of H.10 alloy for the Ministry of Supply. The main objects of the work are:

1. To survey and investigate where necessary the causes and control of cracking and porosity in the metal-arc welding of H.10 alloy using coated electrodes.
2. To determine the relationship between electrical input and thermal cycle for welds in test specimens of finite size, and to provide correlation between thermal cycle, mechanical properties and structure of welded plate.
3. To develop a suitable form of cracking test for use as an acceptance test for coated electrodes, and to give guidance to electrode manufacturers in the development of improved electrodes.

There are three major metallurgical problems, the control and prevention of weld cracking, control of pososity, and the improvement in properties of weld metal and heat-affected zone. All three aspects are affected to some extent by the thermal cycle during welding, which determines the width of the heat-affected zone and the various conditions of heat treatment produced within the zone. The cooling rate will also affect the metallurgical characteristics of the weld metal, that is, the amounts of constituents retained in solution and the amount and distribution of porosity.

For the investigation of the thermal cycle, priority has therefore been given to the mathematical analysis as required under item 2, and a report has been issued to the committee.

The composition of the weld metal is of primary importance in determining the properties of the welded joint. Weld metal dilution by the parent plate has hitherto received little attention. In this case the dilution reduces the silicon content of the weld, and will affect the mechanical properties and cracking tendencies of the weld metal. Further stages in the work are:

1. Review of literature on cracking of aluminium alloys prior to examination of suitable cracking tests.
2. Examination of production components in thick H.10 alloy to ascertain characteristics of weld deposits and extent of dilution effect.
3. Practical tests to confirm results of mathematical analysis.

A panel of the LM.1 Committee has been formed to prepare a Handbook on the Argon-Arc Welding of Aluminium and its Alloys.

Reports to Members

LM.1/8a/46 HAMER, D. J., and BROOKS, H.—Strength Tests on Fusion Welds in Duralumin-Type Alloys.

LM.1/9a/46 MARSHALL, W. K. B.—Welding of some High Strength Aluminium Alloys.

LM.1/11/49 BALL, J. G., and HOULDCROFT, P. T.—Interim Report on an Investigation into the Arc Welding of Thick Aluminium-5 per cent. Magnesium Alloy Plate.

LM.1/18/50 COLE, J. H.—Development of a 600 amp. Argon-arc Torch for the Manual Welding of Thick Aluminium Alloy Plate.

LM.1/20/50 HULL, W. G.—Progress Report on the Development of Equipment of the "Aircomatic" type for Arc Welding Aluminium Alloys.

LM.1/31/52 CHADWICK, J. D., HOULDCROFT, P. T., and HULL, W. G.—Summary of the Investigations into the Metal Arc Welding of Thick Aluminium-5 per cent. Magnesium Alloy Plate.

RB/91/52 NEEDHAM, J. C., and ORTON, L. H.—A.C. Argon-arc Welding at less than 50 V. r.m.s. open circuit.

Published Work

ORTON, L. H., NEEDHAM, J. C., and COLE, J. H.—"The A.C. Argon-Arc Process for Welding Aluminium. The Oscillographic analysis of the application of a Commercial High Frequency Spark-Injection unit," *Welding Research*, **4** (3), 1950, June, pp. 47-68.

COLE, J. H.—"Development of a 600 ampere Argon-Arc torch for the Manual Welding of Thick Aluminium Alloy Plate," *Welding Research*, **5** (2), 1951, April, pp. 157-162.

ORTON, L. H., and NEEDHAM, J. C.—"The A.C. Argon-Arc Process for Welding Aluminium. An Oscillographic Analysis of Effects of Transformer open circuit voltage on Arc re-ignition," *Welding Research*, **5** (6), 1951, Dec., pp. 252-274.

NEEDHAM, J. C., and ORTON, L. H.—"A.C. Argon-Arc Welding at less than 50 V. r.m.s. open circuit," *Trans. Inst. of Weld.*, **15** (6), 1952, Dec., pp. 161-165.

HOULDCROFT, P. T.—"Metal-Arc Welding of Aluminium-Magnesium Plate," *Welding Research*, **6** (6), 1952, Dec., pp. 106-111.

LM.2 COMMITTEE—Development of Strong Aluminium Alloys for Welding

Terms of Reference were—"To develop aluminium alloys with good properties when welded, and to develop improved welding procedure for strong aluminium alloys."

Work by this Committee was discontinued in 1947 when the light alloy committees were re-organised under the two committees LM.1 and LM.3.

Reports to Members

LM.2/14/46 PENDLETON, J.—Gas Welds in a High Strength Aluminium-Zinc-Magnesium-Copper Alloy.

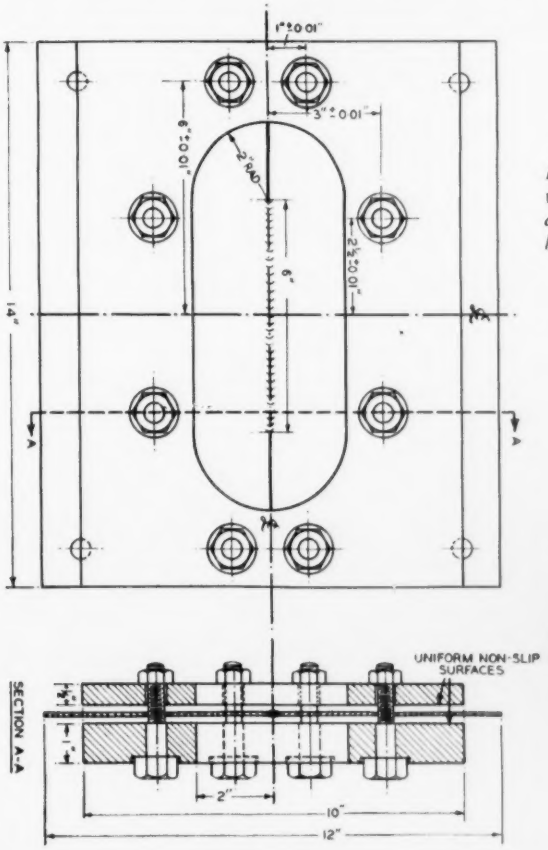
Published Work

PENDLETON, J.—"Gas Welds in High Strength Aluminium-Zinc-Magnesium-Copper Alloy," *Welding Research*, **2** (5), October, 1948.

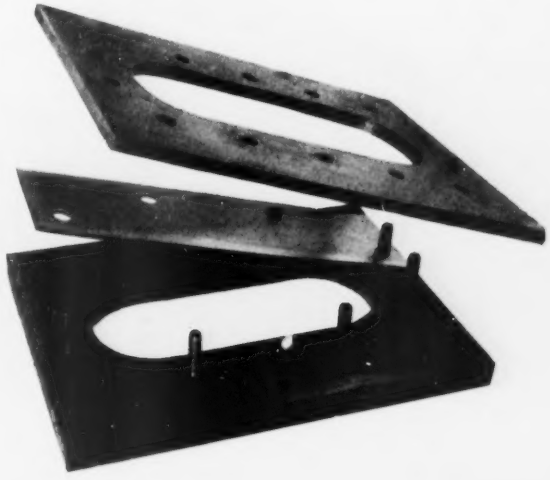
LM.3 COMMITTEE (to Feb. 1952)—Fusion Welding of Magnesium-Rich Alloys

The Committee's terms of reference were:—"To investigate the fusion welding of magnesium-base alloys."

An investigation into the weldability and weld strength of a number of magnesium alloys was completed in 1950 and the results published in 1952. A special jig was designed for the weldability tests, capable of imposing conditions of severe biaxial restraint, as frequently experienced in practice. The materials involved in the investigations were from the following alloy systems:—Mg-Al, Mg-Al-Zn, Mg-Zn-Zr, Mg-Mn, with or without the addition of Ca or Ce. It was shown that the majority of the materials tested could be welded



Restrained weld jig used in work on the weldability of a range of magnesium base alloys. The test sheets were clamped between serrated plates.



by the argon-arc process without serious cracking, whereas several alloys were subject to severe cracking when welded by the oxy-acetylene process. The magnesium-7 per cent. aluminium alloy showed the best combination of weldability and weld strength.

In 1951 a contract was placed with the Association by the Ministry of Supply to investigate certain Mg-Zn-Zr alloys. For this work an automatic controlled-arc unit incorporating a new form of arc-length control system was devised.

REVISED LM.3 COMMITTEE (from 1952)—Welding of Magnesium-Zirconium Alloys and a limited range of other Magnesium-Rich Alloys.

This re-formed Committee was given the following revised terms of reference—"To investigate and devise techniques for the welding of magnesium-rich alloys by the self-adjusting and controlled-arc processes, and to make comparisons with other processes, the alloys to be investigated being confined in the first instance to ZW1, ZW3 and AZ31."

A controlled-arc welding unit has been constructed with several novel features, but extensive welding tests have been delayed owing to the non-availability of plate material and suitable filler wires.

Reports to Members

LM.3/30(a)/46 PENDLETON, J.—The Tensile Strength of Gas Welds in Magnesium-Manganese Alloy to Specification DTD.118.

LM.3/41/46 PENDLETON, J.—Further Examination of the Tensile Strength of Gas Welds in Magnesium-Manganese Alloy to DTD.118.

LM.3/45/48 Test Work on Welded Wrought Zirconium Alloy Sections (Magnesium-Zirconium Alloys).

LM.3/46/48 PENDLETON, J.—The Effect of Misalignment on the Tensile Strength of Gas Welds in Magnesium Base Alloys.

LM.3/50/49 BALL, J. G., WINTERTON, K., and COTTRELL, C. L. M.—Interim Report on Investigations on the Weldability of Magnesium Alloys.

LM.3/54/50 TATE, A. E. L., and BALL, J. G.—The Weldability and Weld Strength of Some Magnesium Alloy Sheet Material.

Published Work

BALL, J. G., and TATE, A. E. L.—"The Weldability and Weld Strength of Some Magnesium Alloy Sheet Materials," *Welding Research*, **6** (1), Feb., 1952, pp. 13-26.

LM.4 COMMITTEE—Recrystallisation Welding

In some early investigations the direct pressure welding of light alloy sheet was tried, but as a result of the difficulties experienced it was decided to concentrate on a research programme on the fundamental mechanism of the process.

As a result of changes in the internal structure of the light alloys committees this committee did not meet, as a separate body, after 1947; the work is now controlled by the Main Light Alloys Committee (RL). (See Miscellaneous Researches, Pressure Welding.)

Reports to Members

LM.4/10/46 TYLECOTE, R. F.—The Pressure Welding of Light Alloy Bar without Fusion.

LM.4/16/47 TYLECOTE, R. F.—Exploratory Work on the Pressure Welding of Copper and Zinc.

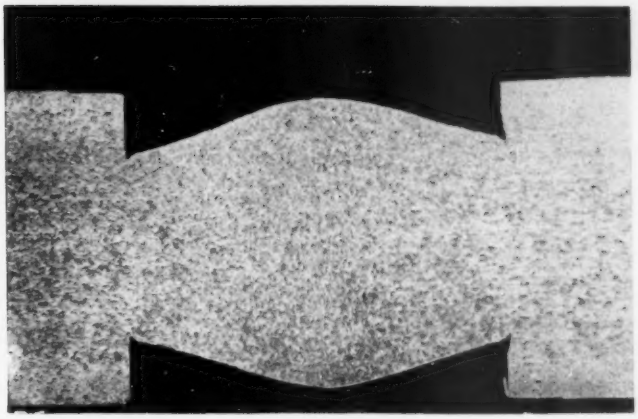
LM.4/17/47 TYLECOTE, R. F.—Further Investigations on the Pressure Welding of Light Alloy Sheet.

LM.4/18/47 TYLECOTE, R. F.—Further Investigations on the Pressure Welding of Light Alloy Bar. (See also Miscellaneous Researches—Pressure Welding.)

Published Work

TYLECOTE, R. F.—"Further Investigations on the Pressure Welding of Light Alloy Sheet," *Welding Research*, **2** (5), Oct., 1948.

TYLECOTE, R. F.—"The Pressure Butt Welding of Light Alloy Bar," *Welding Research*, **3** (1), Feb., 1949.



Pressure butt weld in ½ in. dia. Al-Mn alloy bar made within the temperature range of 600/590 deg. C.

LM.6 COMMITTEE—Testing of Welds in Light Alloys

The committee prepared a review of information on the testing of welds in light alloys and the results were incorporated in a memorandum for publication. After this work the committee was disbanded.

Published Work

"The Testing of Light Alloy Fusion Welds," *Welding Research*, **2** (3), June, 1948; also *B.W.R.A.*, T.19, June, 1948.

LM.7 COMMITTEE—The Self-Adjusting and Controlled-Arc Welding Processes

This new Committee was appointed in 1952 *with the following terms of reference:—"To investigate the characteristics of these welding processes with the object of improving the performance of the apparatus, and to study their application to welded aluminium alloy structures."*

The present research programme covers the following work:—

1. Arc characteristics of the self-adjusting arc process in collaboration with the Electrical Research Association—
   (*a*) Overall relationship between arc voltage, arc length, welding current and burn-off rate.

M.L. "Queen Elizabeth." Owners, Thames Launches Ltd. The superstructure, of N.5 sheet, was welded by the self-adjusting arc process by B.W.R.A. on behalf of The Aluminium Development Association.

(*b*) Mode of metal transfer.
(*c*) Factors controlling the self-adjusting properties of arcs, including power source characteristics.

2. Porosity in self-adjusting arc welds—
(*a*) Effect of rate of cooling and size and shape of weld pool.
(*b*) The effect of surface treatment and composition of plate and filler wire.
(*c*) Development of a reference code for porosity.
(*d*) Effect of porosity on weld properties.

In addition, the practical experience of the members of the committee in the use of the self-adjusting arc is being noted, and special attention is being paid to the protection of industrial personnel from the arc radiation of the self-adjusting arc process.

The effect of power source characteristics has been investigated and has led to a better understanding of the factors affecting the self-adjustment of the arc. In the spring of 1952 the Association was able to carry out practical trials in the welding of the deckhouse for the M.L. "Queen Elizabeth." A film of the work is already generally available and a report is to be published.

Self-adjusting arc process for light alloy research—a portable back-pack unit designed and built in the laboratories of the Association.

Report to Members

LM.7/1/53 HULL, W. G., and NEEDHAM, J. C.—The Self-adjusting arc and Controlled-arc Welding Processes. A Review of Information.

LM.8 COMMITTEE—Welding of High Strength Heat-Treatable Aluminium Alloys

The terms of reference for the work of the Committee are:—"To investigate and develop techniques for the welding of aluminium alloys of the AW.15 and AW.16 types."

A programme of work to be undertaken on behalf of the Ministry of Supply includes the following:

1. Initial investigations on the welding of Al-Cu-Mg-Si and Al-Zn-Mg-Cu alloys of the DTD.683 type using the tungsten-arc process.
2. Detailed investigations of selected alloy systems to discover filler materials stronger than those available at present.

Work is now in progress on a series of special filler wire alloys: Al-Zn-Mg alloys with Cu additions for welding DTD.683, Al-Cu-Si alloys with Mg for welding DTD.646, and Al-Mg alloys with Mn for welding both specifications. A special extrusion press has now been completed to carry out this work and ingots and billets have been prepared.

Engineering Researches

A number of committees mentioned in the following review were active prior to the formation of the B.W.R.A., having been appointed as panels of the Welding Research Council. Most of these were concerned with short-term projects such as the preparation of recommendations for good welding practice; projects which were successfully completed as part of the initial programme of work undertaken by the B.W.R.A. In recent years these committees have been replaced by others set up for the purpose of conducting actual research investigations and this general change in committee activity reflects the growth of the Association's facilities for engineering research.

FE.1 COMMITTEE—Load Carrying Capacity of Frame Structures

The panel on Frame Structures of the Welding Research Council (R42) formed in 1938 was continued by B.W.R.A. as the FE.1 Committee with the following terms of reference:—"The investigation of the actual load-carrying capacities of steel building structures with rigid connections and the development of rational methods of designing such structures."

As a result of the work with which this committee has been associated, the plastic theory is now an established basis of design for certain types of structure. At least three buildings designed by the plastic method have been built, three are in course of construction and several more have been designed and await licences.

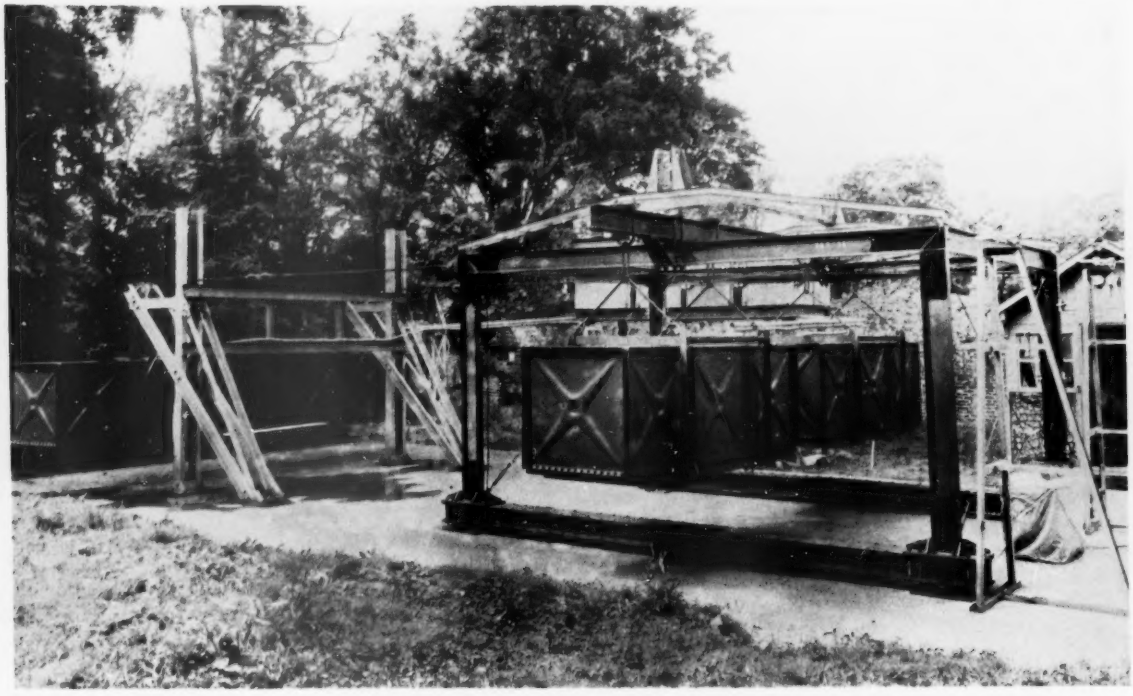
Investigations have been completed into the behaviour in the plastic range of rectangular beams and of rolled steel joists, and the behaviour and design of continuous and fixed ended beams has been considered in detail. Tests on miniature portal frames have confirmed the predictions of the plastic theory for more complicated structures. Full-scale tests have been made on four pairs of portal frames, three tests being on rectangular frames and the fourth on pitched roof frames. This work has established the validity of the simple plastic theory where axial loads are not high and where the beams are supported laterally at intervals not greater than one hundred times the least radius of gyration. The application of the plastic theory to the design of single-storey, single and multi-bay structures has been described, while a Committee of the British Constructional Steelwork Association in collaboration with the B.W.R.A. has produced a handbook, *The Collapse Method of Design.*

The efforts of the committee are now being directed to problems encountered in more complex structures than those dealt with in the above reports. General methods of analysis and design have been put forward but these cannot be used extensively until the problem of instability in continuous structures has been solved. The work on plane stanchions has given a complete explanation of the behaviour of stanchions attached to beams which remain elastic and apply moments about the minor axis only. Sufficient information is now available for the results of this work to be applied to specific examples of design, but the method is only tentative and is still being investigated. Investigations are also continuing into a design method in which the stanchions are assumed to remain elastic whilst the beams become plastic at collapse. Finally, research is proceeding into the behaviour of stanchions subjected to terminal moments about the major axis sufficient to cause partial or complete plasticity. A number of tests have been completed and considerable progress made with the theoretical treatment. Work is also proceeding on the lateral instability of I-beams in the plastic range, continuing the work described in previous reports.

Investigations so far reported have been concerned with rectangular or symmetrical rolled sections. Investigations are now proceeding into the behaviour of built-up I sections, with initial emphasis on the limiting proportions of web plates in the plastic range. An investigation has also started into the bending of channel sections about axes perpendicular to the web as an example of the behaviour of asymmetrical members in the plastic range.

The assumption is made in applying the plastic theory that it is possible to obtain genuinely continuous structures by means of welded joints, the behaviour of which must therefore be investigated. Some work had already been carried out for the FE.2 Committee and also some on the subject of knee-bends for portal frames on behalf of the FE.1 Committee. A new series of investigations into general two-dimensional and three-dimensional beam to stanchion connections in multi-storey frames is just beginning.

Miscellaneous work includes further consideration of fundamentals, general reviews, consideration of wind and floor loads, and the effect of repeated loads.



(Above) *Fixed based portal frame before loading test. The condition of the frame after collapse is shown below.*

Reports to Members

FE.1/1/47 RODERICK, J. W.—Theory of Plasticity—Elements of Simple Theory.
FE.1/2/47 Plastic Design of Single-Bay Portal Frames.
FE.1/6/48 HORNE, M. R.—Discussion on Hrennikoff's Paper on "Inelastic Bending."
FE.1/7/48 RODERICK, J. W., and HEYMAN, J.—Approximate Methods for Calculating Collapse Loads of Stanchions Bent in Double Curvature.
FE.1/8/48 BAKER, J. F., and RODERICK, J. W.—Further Tests on Stanchions—Seventh Interim Report.
FE.1/9/48 HORNE, M. R.—Wind Loads on Structures.
FE.1/10/48 NEAL, B. G.—The Lateral Instability of Mild Steel Beams of Rectangular Cross-Section Stressed Beyond the Elastic Limit.
FE.1/11/48 RODERICK, J. W., and HORNE, M. R.—The Behaviour of a Ductile Stanchion Length when Loaded to Collapse—Eighth Interim Report.
FE.1/12/52 HORNE, M. R.—The Lateral Instability of I-Beams stressed beyond the Elastic Limit.
FE.1/13/48 BAKER, J. F., and HORNE, M. R.—The Effect of Internal Stresses on the Carrying Capacity of a Beam.
FE.1/14/49 RODERICK, J. W., and PHILLIPS, I. H.—The Carrying Capacity of Simply Supported Mild Steel Beams.
FE.1/15/49 RODERICK, J. W., and HEYMAN, J.—Extension of the Simple Plastic Theory to take account of the Strain Hardening Range.
FE.1/17/49 HEYMAN, J.—Tests on Miniature Portal Frames.
FE.1/18/49 HEYMAN, J.—The Determination by Relaxation Methods of the Elasto-Plastic Stresses in Two Transversely Loaded Beams.
FE.1/19/49 HORNE, M. R.—The Variation of Mean Floor Loads with Area.
FE.1/20/49 HORNE, M. R.—The Plastic Theory of Bending of Beams with particular reference to the Effect of Shear Forces.
FE.1/21/49 HORNE, M. R.—Maximum Beam Moments in Welded Building Frames.
FE.1/22/49 HORNE, M. R.—The Effect of Strain Hardening on the Equalisation of Moments in the Simple Plastic Theory.
FE.1/23/50 HORNE, M. R.—Experimental Investigations into the Behaviour of Continuous and Encastered Beams.
FE.1/24/51 RODERICK, J. W.—The Relationship between Load and Deflection for a Partially Plastic Rolled Steel Joist.
FE.1/25/51 RODERICK, J. W.—The Behaviour of Rolled Steel Joists in the Plastic Range.
FE.1/26/51 BAKER, J. F., and RODERICK, J. W.—Tests on Full-Scale Portal Frames.
FE.1/27A/52 FOULKES, R. A.—A Comparison between Elastic and Plastic Designs of Pitched Roof Portal Frames.
FE.1/29/52 HORNE, M. R.—Model to Illustrate the Behaviour of Fixed Base Portal Frames in the Plastic Range.

Published Work

HORNE, M. R.—"A Moment Distribution Method for Rigid Frame Steel Structures Loaded Beyond the Yield Point," *Welding Research*, **1** (1), 1947, p. 6.

BAKER, J. F., and RODERICK, J. W.—"Further Tests on Stanchions," *Welding Research*, **2** (6), 1948, p. 110.

BAKER, J. F., and RODERICK, J. W.—"The Behaviour of Stanchions Bent in Double Curvature," *Welding Research*, **2** (1), 1948, p. 2.

RODERICK, J. W., and HEYMAN, J.—"Approximate Methods of Calculating Collapse Loads of Stanchions Bent in Double Curvature," *Welding Research*, **2** (4), 1948, p. 63.

RODERICK, J. W.—"Theory of Plasticity—Elements of Simple Theory," *Phil. Mag.*, Series **7** (39), 1948, p. 529.

BAKER, J. F.—"A Review of Recent Investigations into the Behaviour of Steel Frames in the Plastic Range," *Journal Institute of Civil Engineers*, **31**, 1948-49, p. 188.

BAKER, J. F., HORNE, M. R., and RODERICK, J. W.—"The Behaviour of Continuous Stanchions," *Proc. Royal Society*, Series A. **198**, 1949, p. 493.

HORNE, M. R.—"The Effect of Variable Repeated Loads in the Plastic Theory of Structures," Colston Research Society, Bristol, *Research Engineering Structures Supplement*, 1949, p. 14.

RODERICK, J. W., and PHILLIPS, I. H.—"Carrying Capacity of Simply Supported Mild Steel Beams," Colston Research Society, Bristol, *Research Engineering Structures Supplement*, 1949, p. 49.

BAKER, J. F.—"The Design of Steel Frames," *Journ. Institute Structural Engineers*, **27**, 1949-50, p. 397.

HORNE, M. R.—"Wind Loads on Structures," *Journ. Institute Civil Engineers*, **33**, 1949-50, p. 155.

RODERICK, J. W., and HEYMAN, J.—"Extension of the Simple Plastic Theory to Take Account of the Strain Hardening Range," *Proc. Institute Mechanical Engineers*.

BAKER, J. F., and HEYMAN, J.—"Tests on Miniature Portal Frames," *Journ. Institute Structural Engineers*, **28**, 1950, p. 139.

BAKER, J. F., and HEYMAN, J.—"Tests on Full Scale Portal Frames," *Proc. Institute Civil Engineers*, Part 1, **1**, p. 71.

NEAL, B. G.—"The Lateral Instability of Yielded Mild Steel Beams of Rectangular Cross-Section," *Phil. Trans. Royal Society*, Series A, **242**, 1950, p. 197.

(*see over page*)

Published Work (*continued*)

HORNE, M. R.—"The Plastic Theory of Bending of Steel Beams with Particular Reference to the Effect of Shear Forces," *Proc. Royal Society*, Series A, **207**, 1951, p. 216.

HORNE, M. R.—"The Effect of Strain Hardening on the Equalisation of Moments in the Simple Plastic Theory," *Welding Research*, **5** (1), 1951, p. 147.

HORNE, M. R.—"The Variation of Mean Floor Loads with Area," *Engineering*, **171**, 1951, p. 179.

BAKER, J. F.—"Comportement et Conception des Ossatures Metalliques," *Revue de la Soudure*, No. 3, 1951.

BAKER, J. F.—"Shortcomings of Structural Analysis" (Twentieth Andrew Laing Lecture), *Trans. N.E. Coast Institute of Engineers and Shipbuilders*, **68**, 1951, p. 31.

BAKER, J. F., and HORNE, M. R.—"The Effect of Internal Stresses on the Carrying Capacity of a Beam," *Engineering*, 1951, p. 212.

HEYMAN, J.—"The Determination by Relaxation Methods, of Elasto-Plastic Stresses in two Transversely Loaded Beams," *Engineering*, **173**, 1952, pp. 359, 389.

HORNE, M. R.—"Experimental Investigations into the Behaviour of Continuous and Encastered Beams." Preliminary Publications, 4th Congress International Association for Bridge and Structural Engineering, 1952, p. 147.

FE.2 COMMITTEE—Strength and Rigidity of Welded Structural Connections

Terms of Reference—"The investigation of the strength and rigidity of welded structural connections and attached components."

Work by the committee had been in progress some time before the inauguration of the B.W.R.A. The research work had been carried out in the Engineering Laboratories, Cambridge University, and in 1948 two reports were submitted. No further work was undertaken by this committee and the investigations of problems relating to the strength and rigidity of welded connections was placed under the guidance of the FE.1 Committee.

Reports to Members

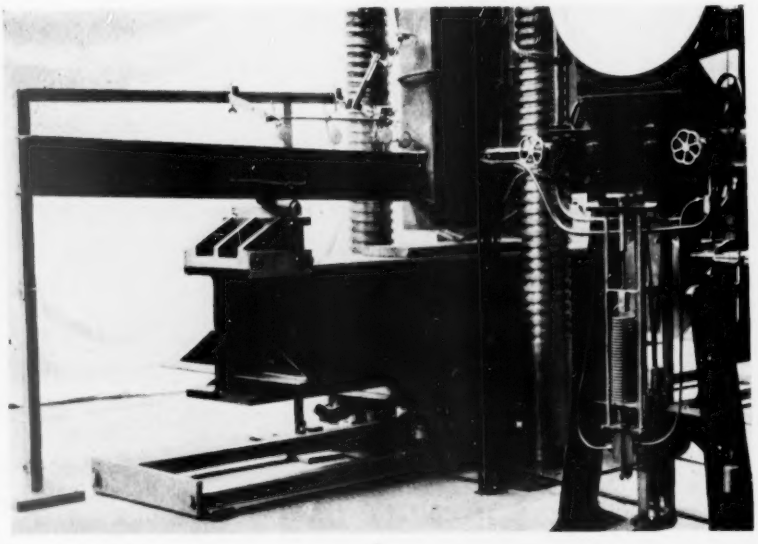
FE.2/7/49 FRANKL, E. K.—Preliminary Tests on Welded Connections.

FE.2/9/50 WAH HING NG.—The Behaviour and Design of Battened Structural Members. *Summary prepared by* HEYMAN, J.

Published Work

FRANKL, E. K.—"Preliminary Tests on Welded Connections," *Welding Research*, **4** (2), April, 1950.

WAH HING NG.—"The Behaviour and Design of Battened Structural Members (*summary prepared by* HEYMAN, J.), *Welding Research*, **5** (3), June, 1951.



Full - scale beam-to-column welded connection on deflection test. 14 *by* 6 *in. R.S.J. stanchion with* 6 *by* 3 *in. beam fillet welded around complete profile to flange of stanchion.*

FE.6 COMMITTEE—Radiography of Welded Pressure Vessels

Terms of Reference—"To consider and investigate aspects of welding radiography as applied to pressure vessels."

The work of this committee was completed in 1948 by the publication of recommendations for standardising the radiographic examination of welded pressure vessels. A memorandum on the photographic aspects of pressure vessel radiography was also published during that year. The committee was superseded by the F.E.18 Committee which had been appointed to deal with the whole field of non-destructive examination of welded structures.

Reports to Members

FE.6/25/47 Recommendations for the Standardisation of the Radiographic Examination of Welded Joints in Mild Steel Pressure Vessels.

Published Work

"Recommendations for the Standardisation of the Radiographic Examination of Welded Joints in Mild Steel Pressure Vessels," *Welding Research*, **1** (3), August, 1947; also *B.W.R.A.*, T24.

MULLINS, L.—"Photographic aspects of the Radiography of Welded High-Pressure Vessels," *Welding Research*, **1** (4), October, 1947; also *B.W.R.A.*, T25.

FE.7 COMMITTEE—Design of Welded Machinery Construction and Parts

Terms of Reference—"To examine and investigate the problems arising in connection with the design and manufacture of welded machinery construction and parts."

The committee's main activities were confined to the preparation of a design memorandum which was completed and published in 1948, following which the committee was disbanded.

Reports to Members

FE.7/11/48 Recommendations for the Design of Arc Welded Mild Steel Machinery Construction.

Published Work

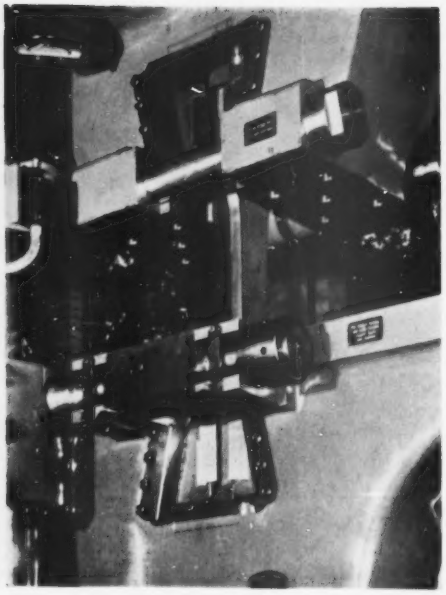
"Recommendations for the Design of Arc Welded Mild Steel Machinery Construction," *Welding Research*, **2** (3), June, 1948; also *B.W.R.A.*, T18.

FE.8 COMMITTEE—General and Fundamental Problems of Fatigue in Welded Structures

The Committee was formally appointed in June, 1946, with the following terms of reference:—"To investigate the problems of fatigue in welded steel structures." At that time work was in progress to advance the application of the resonance vibration method of fatigue testing to large scale welded structures. The potentialities of the method had been proved in two exploratory investigations, in which the specimens used were respectively welded steel H-beams and spot-welded box-section beams in thin gauge aluminium alloy sheet.

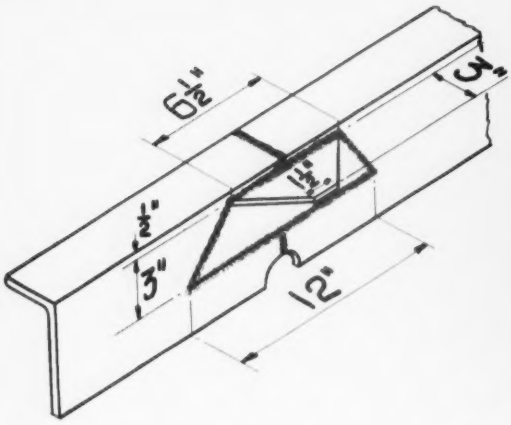
Some early work of the committee was concerned with the influence of residual stresses on fatigue strength, but difficulties in obtaining the use of special induction heating resulted in the research being abandoned in June, 1952. A comprehensive investigation of the fatigue behaviour of stiffened panels, including many different types of welded detail representative of shipbuilding construction was also undertaken under the aegis of a special panel of the committee. This work was supported by The British Shipbuilding Research Association. In 1948 the investigation was transferred to the FE.21 Committee and completed two years later.

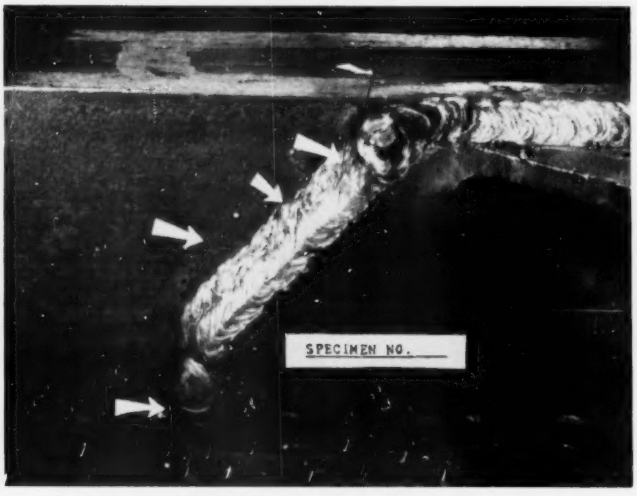
Concurrently with the above investigations two research contracts were accepted. The first was part of a general contract on the development of high-strength low-alloy weldable steels, and comprised fatigue tests on full-scale structural members to examine the influence of micro-cracking on the fatigue strength of fillet welded joints. The second contract called for an investigation of the fatigue behaviour of welded magnesium alloy structures, the design of which incorporated features used in heavy vehicle chassis construction. Work on the second contract started with a comparison of the fatigue strength of magnesium alloy and mild steel



Axial-load fatigue test on mild steel plate specimen in 100-*ton hydraulic machine.*

(Below) *Fatigue testing of butt welded stiffeners. Diagram of reinforcing strap and illustration of fatigue failure.*





structures, and the measurement of the dynamic stresses occurring in a magnesium alloy chassis frame, for various road conditions. The contract has recently been extended to permit a more fundamental investigation to be undertaken, on the fatigue strength of welded joints in magnesium alloys.

An investigation at the Manchester College of Technology, on the fatigue strength of flame-cut, mild steel specimens, started in 1948, was supported by the committee and a report on the work has recently become available.

In 1949 a second panel was appointed by the Committee, to supervise an investigation of the effect of weld faults on the fatigue strength of joints in pipe lines. A third panel was constituted in 1950 to investigate the behaviour of thin-gauge structures.

In 1951 a scheme was adopted whereby the panels of the Committee were set up as independent committees, the FE.8 Committee remaining responsible for the general and fundamental work on fatigue in welded structures, and also acting as the co-ordinating committee for all fatigue investigations undertaken by the Association. It was envisaged that work on light alloys would form an increasingly important part of the general fatigue programme. To define the new activities mentioned above, and also to permit investigations of both ferrous and non-ferrous materials, modified terms of reference were adopted as follows:

> *"To investigate general and fundamental problems of fatigue in welded structures and to advise the RFE Main Engineering Committee on the co-ordination of all fatigue investigations carried out by the group of engineering committees."*

At an early stage of its work, the Committee had sponsored a proposal that the Association should acquire a large capacity hydraulic testing machine to afford facilities for fatigue investigations of a more fundamental kind, and in 1952 a new laboratory was constructed and a 100-ton Losenhausen machine was installed. In the meantime, a long-term programme had been prepared in order to obtain more complete knowledge of the influence of faults on the fatigue strength of metal-arc welded joints in mild steel. As experimental data on the subject were limited, the Shipbuilding Panel (now FE.21 Committee) had inaugurated a preliminary investigation, the results of which were made available to the Committee. The initial part of the programme embraces fatigue tests on two series of flat-plate specimens designed to provide control data. The two series consist of unwelded mild steel plate $\frac{1}{2}$ in. and $1\frac{1}{4}$ in. thick, and butt-welded plates in similar thicknesses, with welds showing the highest radiographic quality.

Reports to Members

FE.8/14/48 WECK, R.—The Application of the Resonance Vibration Method to the Fatigue Testing of Spot Welded Light Alloy Structures.

FE.8.1/7/50 WECK, R.—Effect of Welded Joints on the Fatigue Strength of Panels Stiffened with Angle Stiffeners.

Published Work

PERCIVAL, A. L., and WECK, R.—"Fatigue Tests by the Resonance Vibration Method on Four Welded H-Beams," *Welding Research*, **1**, (2), June, 1947.

WECK, R.—"The Application of the Resonance Vibration Method to the Fatigue Testing of Spot Welded Light Alloy Structures," *Welding Research*, **4** (2), April, 1950.

WECK, R.—"Fatigue Strength of Panels with Welded Angle Stiffeners," *Welding Research*, **5** (5), October, 1951.

FE.10 COMMITTEE—Welded Pressure Pipe Lines

This Committee was originally formed in February, 1939, as the R.121 Panel of the Welding Research Council on The Welding of Pressure Pipe Lines, with the following terms of reference:—"To consider and investigate the welding of pressure pipe lines in mild steel and low-alloy steels, with a view to recommending a technique for producing one-sided butt joints, free from harmful defects." In August, 1941, the panel's Memorandum R.121/8, "Recommendation for Oxy-Acetylene Butt Welds in Mild Steel Pressure Pipe Lines," was published. (The latest edition of this is B.W.R.A. Technique Memorandum T5, 3rd edition, 1946.) The terms of reference were modified in July, 1944, to read:—"To consider and investigate problems relating to the welding of pressure pipe lines in mild and low-alloy steels." The panel was subsequently re-appointed by the B.W.R.A. as the FE.10 Committee on Welded Pressure Pipe Lines.

One of the committee's first activities was the revision of Memorandum R.121/8, based on extensive investigations of normalising procedure and on methods for applying the bend test to pipe joints.

After this work the committee went on to prepare a memorandum on the metal-arc welding of butt joints in pressure pipe lines. This memorandum was completed and circulated to members in 1950 and the recommendations were made available to the British Standards Institution for use in the preparation of a specification on arc welded pipe lines.

The committee discussed the preparation of a memorandum on the welding of branch pipes and were of the opinion that, before recommendations for the design and welding of branch pieces could be formulated, a number of aspects of the problem required investigation. A joint panel of members of FE.10 and FE.16 Committees has been set up to draft a programme of work. This panel has submitted its report and work is being carried out by the FE.16 Committee. The FE.10 Committee has now been disbanded.

Reports sent to Members and later published

"Recommendations for Oxy-Acetylene Butt Welds in Mild Steel Pressure Pipe Lines," *B.W.R.A.*, T5, Third edition, September, 1946.

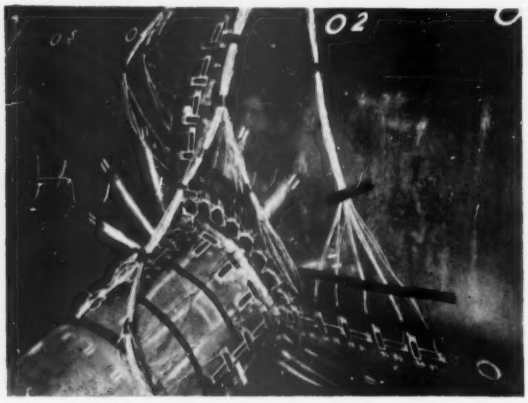
"Recommendations for The Metal-Arc Welding of Butt Welds in Steel Pipe Lines for Power Plant," *Welding Research*, **4** (3), June, 1950; also *B.W.R.A.*, T23.

FE.12 COMMITTEE—Stresses in Welded Pressure Vessels

The committee was formed in 1944 *by the Welding Research Council, to carry out investigations on the distribution of stresses in welded pressure vessels with a view to the determination of the allowable working stresses in the welded joints. However, in* 1946, *it was finally agreed that it was not part of the committee's work to make specific recommendations regarding permissible stresses, and the following terms of reference were then adopted:—"To carry out investigations on the distribution of stress in welded pressure vessels with the object of providing knowledge of the stresses to be considered in design."*

Experimental work on the measurement of stresses in welded pressure vessels was started by Messrs. Babcock and Wilcox Ltd., who reported to the committee the results of a comprehensive investigation of a full-size vessel. In this single investigation, stresses were measured at all important locations on the vessel, both external and internal, these including measurements in a plain drumhead and a man-hole drumhead, in a cylindrical shell of slightly non-circular form, and at positions near nozzles and tube holes. Stresses given by theoretical calculations were produced for comparison with the measured values. In addition to the considerable amount of data obtained from the work, a valuable and original contribution was made to the technique of measuring strains on the inside surfaces of a vessel subjected to internal pressure.

Interim reports on the above investigation were considered by the committee and later combined to form a published report. In considering the significance of the experimental results, the committee came to the conclusion that the outstanding problem in the field of pressure vessel research was the stress distribution in, and adjacent to, welded nozzle attachments. It was agreed that work on this subject should be undertaken by the Association, using a vessel of special design, and the planning of tests was considered at some length. The donation of a suitable vessel by Messrs. John Thompson Ltd. enabled the committee to finalise the design and test procedure for a first series of experiments in which the stresses were to be measured in and near three nozzle attachments, without any form of added reinforcement, no other discontinuities being introduced into the shell. The three nozzles were made equal in internal diameter, but different in wall thickness to give an indication of the amount of reinforcement obtained by thickening the nozzle attachment. The omission of compensating plates at the nozzle openings was proposed in order that a fundamental study of the weakening effect of such openings could be made, providing information which would serve as a datum for later tests on reinforced nozzles.



Electric resistance strain gauges bonded to a pressure vessel for the determination of the stresses around the welded-in nozzle.

Strain measurements on this vessel were carried out and a summary of results has been considered by the committee. These results are now being used to check the general theory and to distinguish the reinforcement provided by nozzles of different thickness. For the second stage of the investigation the committee has agreed in principle that experimental measurements of the stress systems occurring in reinforced nozzles should be undertaken. A panel of the committee has now worked out design details for reinforced nozzles which will enable a special study to be made of the effect of the disposition of reinforcing material around a nozzle opening.

In addition to the examination of reinforcement designs, the panel was also asked to consider details for an investigation to determine the relative efficiency of partial and full penetration welds between nozzle and shell, under conditions of pulsating pressure. This problem was brought to the notice of the committee by two manufacturers, and it was agreed that it could be regarded as a subject within the present field of investigation, since fatigue tests of reinforced nozzle assemblies would undoubtedly form a later stage of the work and tests on nozzle welds would provide useful basic information. A series of nozzle weld designs have been prepared and approved by the Committee.

Reports to Members

FE.12/20/51 Experimental and Analytical Determination of the Stress Systems in a Welded Pressure Vessel, by a research team of Babcock & Wilcox Ltd.

Published Work

"Experimental and Analytical Determinations of the Stress Systems in a Welded Pressure Vessel," *B.W.R.A., also Babcock & Wilcox Ltd.*, 1951.

Stress-Probing: "A Rapid Method for Stress-Surveying," *Engineering*, **174** (4513), July, 1952.

"An Accurate Wire Resistance Method for the Measurement of Pulsating Pressures," *Journal of Scientific Instruments*, **30**, pp. 1-2, January, 1953.

FE.13 COMMITTEE—Codes of Practice for Welded Building Structures

Terms of Reference—"To prepare clauses for inclusion in Codes of Practice on the Application of Welding to Building Structures, with particular reference to the requirements of Design, Fabrication and Erection."

By 1946 the committee had completed its Recommendations on "Stanchion Bases, Caps and Joints" and "Built-up Girders and Compression members," and in the following year these were published. The preparation of a third memorandum was then undertaken. This dealt with the design, fabrication and erection of metal-arc welded mild steel building structures, and as it included general recommendations of considerable scope, it was used extensively for the revision of national codes of practice dealing with building structures. To complete this series of memoranda, the committee drew up recommendations for the design of Beam and column connections. The committee has now been disbanded.

Reports to Members

FE.13/37/46 Arc Welded Structural Steelwork—II. Built-up Girders and Compression Members. Recommendations for the Design and Fabrication of Welded Members.

FE.13/43/47 Recommendations for the Design, Fabrication and Erection of Metal-arc Welded Mild Steel Building Structures.

FE.13/52/50 Beam and Column Constructions, Recommended Design for Metal-arc Welded Building Structures.

Published Work

"Arc Welded Structural Steelwork —I. Stanchion Bases, Caps and Joints," *Welding Research*, **1** (1), April, 1947; also *B.W.R.A.*, T17, March, 1946.

"Arc Welded Structural Steelwork—II. Built-up Girders and Compression Members. Recommendations for the Design and Fabrication of Welded Members," *Welding Research*, **1** (3), August, 1947; also *B.W.R.A.*, T26, 1950.

"Recommendations for the Design, Fabrication and Erection of Metal-arc Welded Mild Steel Building Structures," *Welding Research*, **1** (4), October, 1947.

"Recommended Designs for Metal-arc Welded Mild Steel Building Structures. Beam and Column Connections," *B.W.R.A.*, T28, 1952.

FE.14 COMMITTEE—Heat Treatment of Welded Constructions

Terms of Reference—"To investigate the necessity for and the effect of heat treatment on welded steel construction and to draw up recommendations for the method of carrying it out."

The work of the committee was not continued after 1947 and the committee remained in abeyance until 1950 when it was formally disbanded with the recommendation that it be reconstituted should occasion arise. During its active period the committee prepared recommendations on the heat treatment of arc welded mild steel constructions, and this work was published.

Published Work

"Recommendations for the Heat-Treatment of Welding Constructions in Mild Steel," *Welding Research*, **1** (2), June, 1947; also *B.W.R.A.*, T20, Second edition, October, 1950.

FE.15 COMMITTEE—Specifications for Electrodes

Terms of Reference—"To prepare a specification covering the classification, quality, testing and other requirements, as necessary, of covered electrodes for the metal-arc welding of mild steel."

The committee undertook a considerable amount of work in connection with the testing of electrodes for the arc welding of mild steel. The results of this work were embodied in a set of recommendations which later formed the basis for the revision of British Standard 639. The committee was disbanded in 1949 on the completion of this work.

FE.16 COMMITTEE—Pipe Connections and Fittings Fabricated by Welding

The terms of reference of the committee, adopted at its first meeting in 1946, *are: "To investigate the design and strength of pipe connections and fittings which are fabricated by welding, with particular reference to oil installations."*

The first problem to which the committee gave its attention was that of the distribution of stresses in pipe bends, and a programme of experimental work was drawn up with a view to comparing seamless bends with pressed, welded bends, under the following loading conditions:—

(*a*) Static internal pressure.
(*b*) Static bending, reducing the radius of curvature.
(*c*) Combined internal pressure and static bending.

In planning the work the committee attached considerable importance to the need for obtaining fundamental information on the distribution of stress in pipe bends, which would enable an assessment to be made of the accuracy of existing theories on this subject.

Experimental work was put in hand after the first meeting and continued until the end of 1951. The first part of the investigation was confined to the static internal pressure and static bending tests applied to short-radius, 6-in. diameter bends of both seamless and welded type. A pipe bend of this size was also used later for experiments in which the two loading conditions were combined. In 1949 a contract arrangement with the Admiralty and the Imperial College permitted an additional series of tests on the flexibility of pipe bends to be undertaken, giving information on a wider range of values of the pipe factor. From the results of all the investigations, a simple and reliable method for calculating safe working conditions was derived. This work has been published.

During 1949 the Committee joined with the FE.10 Committee to examine the need for experimental work on branch connections in welded pipe lines. As a first step a review of the literature was made, and confirmed that very little information on the stresses in branch connections was available. A programme of research was therefore prepared and a panel of the FE.16 Committee was delegated to proceed with the work. It was agreed that the experimental programme should deal comprehensively with the measurement of stresses in connections reinforced

Welded branch connection in concrete test pit being subjected to internal pulsating pressure.

in different ways so that the essential requirements of reinforcement design might be evaluated.

As a basis to the investigation, the committee and panel planned a series of tests on unreinforced welded tees and intersection branches, to obtain experimental measurements of the stresses occurring under many forms of loading (e.g. internal pressure, external bending and torsion moments on the branch piece). The work has now reached the stage where the first tests on reinforced branch connections are being undertaken for similar loading conditions. Recently the committee itself has assumed responsibility for the continuation of the branch connection tests, and, in addition, has planned further work on pipe bends, including pulsating pressure fatigue tests on short-radius bends, and the measurement of stresses in lobster-back bends.

Reports to Members

FE.16/9/51 GROSS, N.—Experiments on Short-Radius Pipe Bends.
FE.16/14/52 GROSS, N.—A Test on a Pipe Bend subjected to External Loads and Internal Pressure Simultaneously.
FE.16/15/52 GROSS, N.—A Simple Method for Estimating the Load Factor in Curved Pipes.

Published Work

GROSS, N.—"Experiments on Short-Radius Pipe Bends," *Engineer and Foundryman* (S.A.), **17** (7), November, 1952; also *Combustion Engineering*, **7** (3), March, 1953; also advance paper, *Institute of Mechanical Engineers*, December, 1952.

GROSS, N., and FORD, P. H.—"The Flexibility of Short-Radius Pipe-Bends," advance paper, *Institute of Mechanical Engineers*, December, 1952.

FE.17 COMMITTEE—Faults in Arc Welds

The committee was appointed in October, 1946, to prepare a memorandum defining the faults which can occur in arc welds in steel construction. This work was completed by 1949 and published in *Welding Research*, as a B.W.R.A. Technique Memorandum and as a wall-chart, and has been very well received by industry.

Reports to Members

FE.17/6/43 Memorandum on Faults in Arc Welds in Mild and Low-Alloy Steel.

Published Work

"Faults in Arc Welds in Mild and Low-Alloy Steel," *Welding Research*, **4** (1), February, 1950; also *B.W.R.A.*, T22, 1950 (second printing), and as a Wall Chart, 1951.

FE.18 COMMITTEE—Non-Destructive Methods for the Examination of Welds

The first meeting of the Committee was held in April, 1947, when the following terms of reference were adopted:—"To consider and investigate methods for the non-destructive examination of welds and to make recommendations for the development and application of such methods in the inspection and testing of welded steel construction."

An extensive survey was made of the various non-destructive methods of examination, and in 1951 the Committee issued a Memorandum on Non-Destructive Methods for the Examination of Welds. This was subsequently published.

No further work has been undertaken by this Committee, but considerable progress has been made with a Government contract on the application of the ultrasonic method to the examination of welds, and it is hoped that it will be possible to report on this work at an early date.

Reports to Members

FE.18/14A/51 Memorandum on Non-Destructive Methods for the Examination of Welds.

Published Work

Memorandum on Non-Destructive Methods for the Examination of Welds, *B.W.R.A.*, T29, 1952.

FE.19 COMMITTEE—Influence of Residual Stresses in Welded Structures

In 1948 the Association set up an informal committee to make an appraisal of the existing knowledge on the influence of residual welding stresses. A paper on this subject by Dr. R. Weck had been read at the inaugural meeting of the International Institute of Welding, the discussion on which revealed a wide divergence of views amongst research workers. Many research institutions were supporting the need for knowledge of more fundamental aspects of the influence of residual stresses on fatigue strength and brittle fracture, and in recognition of this the International Institute appointed a Technical Commission in 1948 to make a study of the general problem. The B.W.R.A. committee was linked with this Commission and undertook to review the position in this country.

The discussions of the committee led to the unanimous conclusion that, while failures of welded structures had been ascribed to deleterious effects of residual stresses, it was not possible with the existing state of knowledge on the subject to appreciate the role of such stresses in many of the known cases. With the need for experimental investigations firmly established, it was recommended that as a first step a permanent committee should be appointed to formulate and carry out the necessary research. This recommendation was subsequently approved and the FE.19 Committee was brought into being in June, 1949, with the following terms of reference:—

"To investigate the influence of residual stresses in welded steel structures."

Two aspects of the general problem, regarded of major importance, have been given attention. These are:—

(1) The influence of residual welding stresses on fatigue strength.

(2) The influence of residual stresses on brittle fracture.

In discussions on the first problem, the committee has arrived at a general conclusion that no entirely satisfactory evidence has been produced, from the many investigations carried out, to show that residual stresses have any influence on fatigue strength. Such an influence may possibly be shown experimentally, but the conditions required would, in all probability, demand a difficult experimental technique.

It was considered that useful information might be obtained from fatigue tests on specimens containing very severe local stresses, and experiments of this kind were put in hand. To obtain the stress system required, relatively small weld beads were deposited on heavy shaft specimens, which were afterwards subjected to alternating bending tests. The results given by "as-welded" and stress-relieved specimens, were not, in the committee's view, capable of interpretation in terms of the independent effect of residual stresses, being complicated by the fact that some failures had clearly been associated with welding faults. Investigations carried out elsewhere also indicated the difficulty of devising a test, particularly on a welded specimen, in which it could be supposed that residual stresses exercised an effect more pronounced than those arising from other factors. No further work has been planned on this aspect of the problem.

With regard to the second aspect—the influence of residual stresses on brittle fracture—the committee decided that experimental work was necessary. It was known that investigations of the same problem had been carried out elsewhere, but it was considered that more definite conclusions might be obtained from tests in which the principal factors were better controlled. To assist in defining certain features of the problem, an exploratory series of tests was carried out by Dr. R. Weck and Mr. P. Whitaker. These tests demonstrated that spontaneous brittle fracture of a welded assembly under very severe restraint, and in the presence of a notch, could not be obtained unless the temperature of the material was reduced far below its transition temperature, as normally assessed by the Izod test. Such conditions were realised for one type of material, and brittle fractures were produced, but the committee was not entirely satisfied that in these experiments the test conditions were free from extraneous effects.

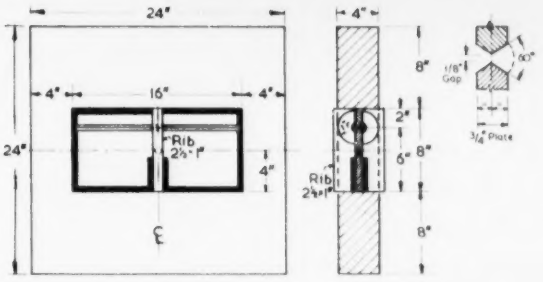
As part of the work of the committee, contact with the activities of the I.I.W. Commission has been maintained, and recently some experiments have been started to provide data for an investigation in which other represented countries are taking part. This investigation seeks to show the influence, or the efficiency, of different kinds of stress-relieving treatment. The experiments envisage controlled impact tests on plain and notched plates into which residual welding stresses have been introduced, and on other specimens given a thermal or mechanical stress-relieving treatment before testing.

Reports to Members

FE.19/5A/51 WECK, R.—Experiments on Brittle Fracture of Steel Resulting from Residual Welding Stresses.

Published Work

WECK, R.—"Experiments on Brittle Fracture of Steel Resulting from Residual Welding Stresses," *Welding Research*, **6** (4), August, 1952.



Tests on the brittle fracture of steel due to residual welding stresses. (Above) *Cooling chamber using CO_2 and liquid oxygen to give a controlled cooling rate down to 70 deg. C.* (Left) *Form of test piece for restrained butt weld with central rib.*

FE.20 COMMITTEE—Tests on Welded Chains

This committee was formed in March, 1953, with the following terms of reference:—"To develop a test for welded chains for specification purposes."

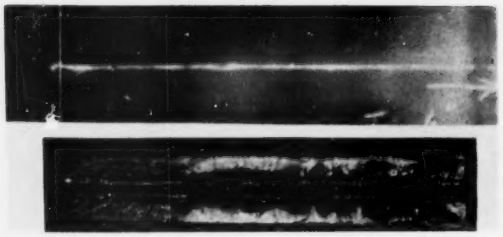
The Association was asked to investigate the welding of chains, as views were held that the tests at present prescribed were not sufficiently discriminating and that this was prejudicial to the use of such chains. The Committee has already planned a first programme of work, the object of which will be to determine the suitability and reliability, not only of tests at present prescribed, but also of certain other tests.

FE.21 COMMITTEE—Behaviour of Welded Ship Structures under Fatigue Loading

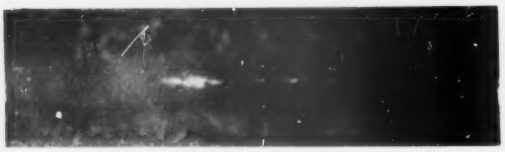
Terms of Reference—"To investigate problems of fatigue in welded ship structures."

The effect of some common weld faults on the fatigue strength of mild steel butt welds was examined in a series of exploratory tests carried out by the Naval Construction Research Laboratory, Rosyth. Although

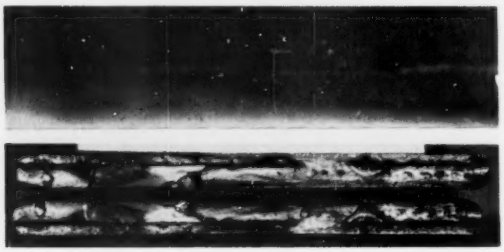
Specimen containing heavy slag patches. Fatigue life 62,810 cycles at ±8·0 tons per sq.in.



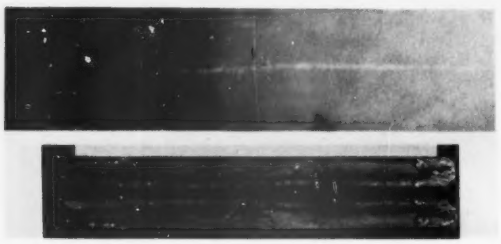
Specimen showing heavy slag line at root. Fatigue life 211,390 cycles at ±8·0 tons per sq.in.



X-radiograph of specimen which fractured away from the weld at 801,380 cycles at ±8·1 tons per sq.in.



Also showing slag line at root. Fatigue life 1,082,610 cycles at ±8·0 tons per sq.in.



Specimen with fatigue life of 49,370 cycles at ±7·9 tons per sq.in. X-radiograph shows heavy parallel slag lines.

Fatigue tests on defective butt welds. Illustrations of X-radiographs and actual fractured surfaces.

these tests were carried out with the object of using the limited experimental data to plan a more extensive investigation, it was felt that the results would be of wide interest and the results have been published.

The committee is in abeyance, but is associated with the FE.8 Committee in the investigation of the fatigue strength of welded joints in mild steel plate.

Published Work

WARREN, W. G.—"Fatigue Tests on Defective Butt Welds," *Welding Research*, **6** (6), December, 1952.

FE.22 COMMITTEE—Behaviour of Welded Joints in Pressure Pipe Lines under Fatigue Loading

The Committee was originally constituted in May, 1950, as a panel of the FE.8 Committee, with the following terms of reference:—"To investigate the effect of weld imperfections on the mechanical properties of welded joints in pressure pipe lines, with particular reference to fatigue strength."

The appointment of the panel arose from the discussions of the FE.10 Committee concerning the need in industry for guidance on weld quality requirements in high-duty pipe line systems and particularly the need for guidance on acceptable radiographic quality. The problem was referred to the FE.8 Committee since an investigation by fatigue testing methods was envisaged.

Under the re-organisation of the FE.8 Committee, which took place in 1951, the panel was reconstituted as the FE.22 Committee.

The original programme of work of the panel included fatigue tests on 6-in. diameter unwelded pipes and pipes containing artificial imperfections to obtained control data, but the latter idea was abandoned in

favour of testing actual welds, and the programme was recast to include tests on arc- and gas-welded butt joints. It was decided that, initially, tests should be made on joints showing the highest radiographic quality; the means of producing imperfect welds for subsequent tests was deferred until after the completion of the work on high-grade welds. The first part of the programme is now completed; tests on the welded and unwelded pipes have been carried out with two kinds of fatigue loading, pulsating pressure and alternating bending. As a subsidiary part of the pulsating pressure tests on pipes, experiments have been carried out with various types of end-closure to select a design that would be satisfactory under the loading conditions applied and would not be expensive to manufacture.

Reports to Members

FE.22/2/52 GROSS, N., and LANE, P. H. R.—Pulsating Pressure Tests on Flat End Closures for Small Diameter Vessels.

FE.23 COMMITTEE—Behaviour of Welded Thin-Gauge Constructions under Fatigue Loading

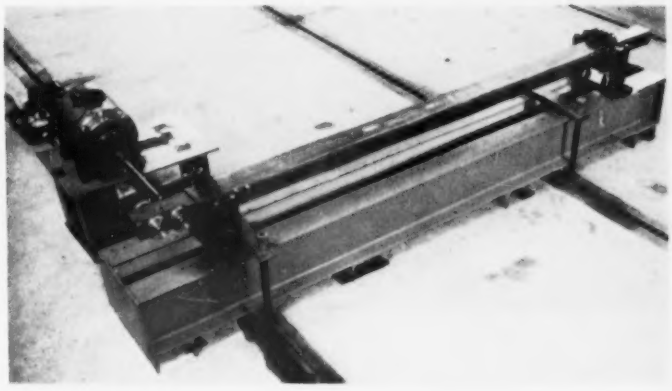
The Committee was formed in 1951, *originally with the status of a panel of the FE.*8 *Committee. In the same year it was reconstituted as a full committee, having the following terms of reference:—"To investigate the fatigue strength of resistance-welded and arc-welded constructions in thin gauges of mild steel sheet."*

It was intended, as these terms state, to confine any investigations to mild steel constructions. However, the Research Board later approved a suggestion that the committee should be free to consider parallel work on welded light-alloy structures, and the terms will need modification when such work is inaugurated.

The original panel was appointed primarily to consider fatigue problems in vehicle structures, with particular reference to the pressed and welded box-section type of construction used for motor-car chassis frames. A programme of work embodying the fatigue testing of simple box-section beam specimens was therefore planned. The simple specimens were preferred for the initial stages of the investigation, but it was recognised that since many of the practical problems involve the fatigue behaviour of complicated structural elements—or even complete chassis frames—an extension of the work in this direction will become desirable.

Five types of beam specimen were selected for the first tests. These were of rectangular cross-section and were constructed from 16 s.w.g. mild steel. In order to obtain a measure of the efficiency of different kinds of welded construction, three welding processes were used for fabricating the beams, resistance spot welding, metal-arc welding and automatic carbon-arc welding. The fatigue test conditions required were alternating bending and alternating torsion.

Specimens for the bending tests were supplied by five chassis manufacturers and the experimental work on these specimens has continued during the past year. A first interim report has been prepared and the planning of further work, including similar tests on light-alloy structures, is under consideration.



Resonance vibration unit for carrying out alternating bending tests on thin gauge box-section beams.

Resistance Welding Researches

The resistance welding researches of the B.W.R.A. are under the general guidance of the Main Resistance Welding Committee, formerly the Main Ferrous Metals (Resistance Welding) Committee, whose terms of reference are "The Main Resistance Welding Committee will be responsible on behalf of the B.W.R.A. for the initiation and conduct of research in all matters relating to resistance welding. The Main Committee is empowered to appoint such committees and panels as it may find necessary for the proper discharge of its terms of reference."

FR.3 COMMITTEE—Projection Welding of Steel

The terms of reference of this Committee are: "To determine the conditions for projection welding ferrous material."

This committee continued earlier experimental work on projection welding in sheet steel, to determine the best properties which could be obtained by projection welding, using a single projection. Tests were then made using two and three projections, with a comparison of the quality of results with that for single projection welds. It was shown that high-quality joints could be produced by accurate control of the welding machine and of projection heights.

The committee has now prepared a Code of Practice for projection welding, based largely on the above work. A research programme has also been carried out on the projection welding of bolts (or headed studs) to sheet material, to determine the most suitable relationship between the radius of the projection on the head, and the shank diameter. In these experiments statistical techniques were extensively applied. A provisional standard design for studs produced by cold heading has been evolved.

Further experimental work is required on projection welding of dissimilar thickness sheets, and to extend the range covered in the code of practice to 24 s.w.g. and $\frac{1}{8}$ in. at the lower and upper thicknesses respectively. Tests are also required on the welding conditions necessary for the use of annular projections, as used for welding nuts, bolts and bosses to sheet.

Reports to Members

FR.3/22/47 HIPPERSON, A. J.—Mechanical Properties and Welding Characteristics of Single Projections in Low-Carbon Mild Steel Sheet (with particular reference to 14 s.w.g. thickness).

FR.3/57/52 DIXON, H. E., and ROBERTS, J. E.—Torsion Impact Testing of Stud Welds in Low-Carbon Mild Steel.

FR.3/64/52 ROBERTS, J. E.—Triple Projection Welding of Deep Drawing Quality Steel Sheet.

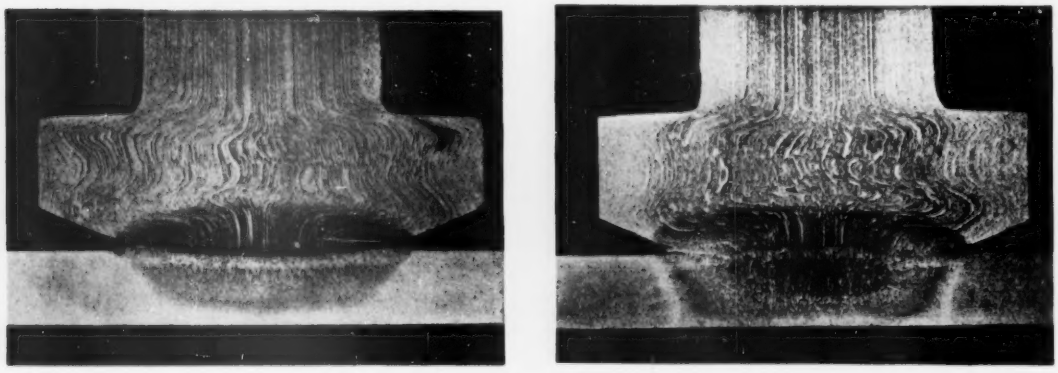
FR.3/65/52 ROBERTS, J. E.—Resistance Welding of Cold-Headed Bolts.

FR.3/67/52 HIPPERSON, A. J., and ROBERTS, J. E.—Single Projection Welding in 16, 18 and 20 s.w.g. Mild Steel.

Published Work

HIPPERSON, A. J.—"Mechanical Properties and Welding Characteristics of Single Projections in Low-Carbon Mild Steel Sheet, with Particular Reference to the 14 s.w.g. Thickness," *Welding Research*, **2** (4), August, 1948.

ROBERTS, J. E.—"Resistance Welding of Cold-Headed Bolts," *Welding Research*, **6** (6), December, 1952.



(*a*) (*b*)

Photomacrographs of bolts welded to sheet. (a) pressure weld type; (b) fused weld type.

FR.4 COMMITTEE—Flash Welding of Steel

Terms of Reference—"To investigate the physical and metallurgical processes involved in flash welding alloy steels, and to determine conditions for producing satisfactory welds in selected steels."

The main activity of the Committee was to produce a memorandum on the flash welding of steels. This work was completed in 1950, *and the memorandum was issued.*

The committee has only met once since 1950, to discuss the problem of welding tubing without any internal flash. No experimental work is in progress, but individual committee members are carrying out development work. In the meantime, the Committee is in abeyance, but is available for consultation should the need arise.

Reports to Members

FR.4/16A/50 Industrial Use of Flash Welding, Dealing in Particular with Ferrous Materials.

Published Work

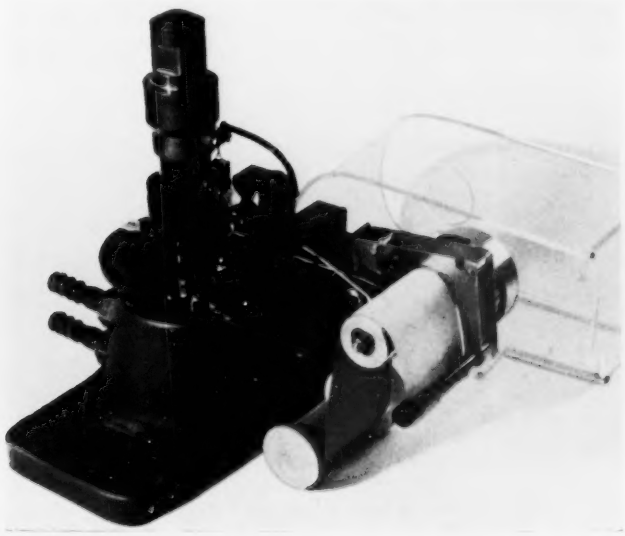
"Industrial Use of Flash Welding, Dealing in Particular with Ferrous Materials," *Welding Research*, **5** (1), February, 1951; *Canadian Eng.*, **62**, (6), (7), (8), 1951; also *B.W.R.A.*, T.27.

FR.5 COMMITTEE—Development of Devices for Recording Current, Pressure and Time in Resistance Welding

Terms of Reference—"To develop simple and accurate equipment for measuring current, pressure and time in resistance welding machines."

Early work of the Committee was directed towards the development of a mains operated valve voltmeter and the alternative instrument an impulse ammeter for the measurement of secondary current. The Committee also developed a cycle recorder, known as the "cyclegrapher" which has been marketed by an instrument manufacturer.

Later work was concerned with the testing of a spring-loaded stake for measuring electric load and the construction of a prototype instrument to measure current and load simultaneously during spot welding. This instrument is now on test and provisional patents have been filed. The method uses a liquid-filled diaphragm and Bourdon tube to measure electrode load, and a D.C. energised coil parallel to the electrode to measure current, both measurements being recorded directly on waxed paper. After completing the work,



Spot welding current and load recorder for workshop use, designed and built in the Association's laboratories for the F.R.5. Committee.

the Committee will be disbanded, the final report being a full review of methods of instrumentation which have been tested, both those which were successful and those which were not.

Reports to Members

FR.5/8/46 First Interim Report of Committee.
FR.5/12/46 HIPPERSON, A. J.—A Mains Operated Valve Voltmeter for the Measurement of Secondary Current in Resistance Welding.

Published Work

"Instruments for the Measurement of the Main Variables in Resistance Welding Machines," *Welding Research*, **1** (5), December, 1947.
HIPPERSON, A. J.—"A Mains Operated Valve-Voltmeter for the Measurement of Secondary Current in Resistance Welding Machines," *Welding Research*, **2** (3), June, 1948.

FR.6 COMMITTEE—The Preparation of a Code of Practice for Spot Welding Mild Steel

Terms of Reference—"To prepare a code of practice for the spot welding of mild steel."

This Committee issued a restricted code of practice in 1948, and then further experimental work was carried out to extend the range of material thickness covered in the code, to cover 24 s.w.g. and $\frac{1}{8}$ in. thick steel. This has been incorporated in a revised Code of Practice.

Additional experiments were made to determine the effect of minor factors on spot weldability; these covered the method of manufacture (basic O.H. and basic Bessemer rimming steels, and a basic O.H. fully-killed steel), and the treatment, particularly the effect of a final 1 per cent. cold reduction after annealing. Limited tests were made on the welding of $\frac{3}{16}$ in. and $\frac{1}{4}$ in. thick material, the results of which have been reported. Some work on spot welding of zinc-coated steel was reported to the Committee, and a review of information on resistance welding of steels with protective coatings has been completed.

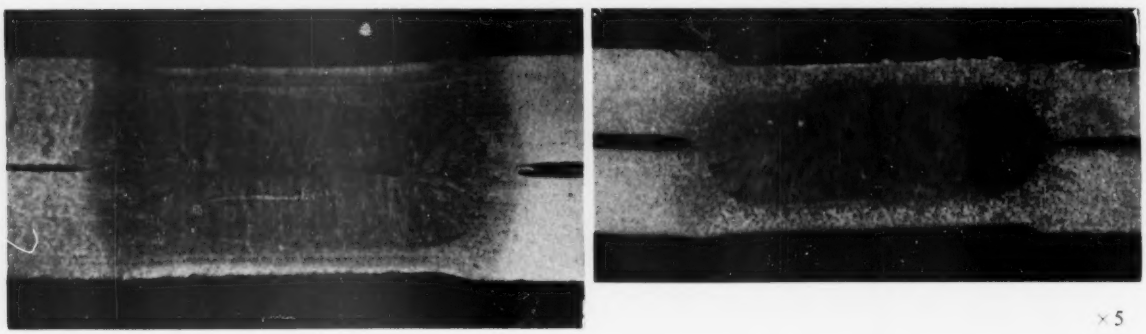
It is intended that the Committee will be disbanded during the year 1953-54, after having had an opportunity to discuss any comments received on the published revised Code of Practice (T21A).

Reports to Members

FR.6/17/47 Interim Report—Recommended Practice for the Spot Welding of Mild Steel Sheet.
FR.6/31/52 DIXON, H. E., and ROBERTS, J. E.—Spot Welding of 24 s.w.g. S.84 Steel Sheet.
FR.6/33/52 DIXON, H. E., and ROBERTS, J. E.—Spot Welding of $\frac{1}{8}$ in. thick mild steel.
FR.6/34/53 ROBERTS, J. E., and DIXON, H. E.—The Effect of Steel Quality on Spot Welding Properties.

Reports Published

"Recommended Practice for the Spot Welding of Low Carbon Mild Steel Sheet," *Welding Research*, **2** (5), October, 1948; also *B.W.R.A.*, T21 (1949).
HIPPERSON, A. J., and TEANBY, P. M.—"Spot Welding of Coated Mild Steel Sheet," *Welding Research*, **5** (6), December, 1951.
DIXON, H. E., and ROBERTS, J. E.—"Spot Welding of Low Carbon Steels—24 s.w.g. and $\frac{1}{8}$ in. Thick," *Welding Research*, **7** (1), February, 1953.



(*a*) ×8 (*b*) × 5

Spot welding of coated sheets: (a) 200th weld (without electrode dressing) in cadmium-plated sheet, (b) weld in zinc-coated sheet.

FR.7 COMMITTEE—Fundamentals of Resistance Welding

The Committee was set up in 1951 *with the terms of reference:—"To investigate the fundamental aspects, both physical and metallurgical, of spot welding ferrous materials," that is, the relationship between energy input and heat distribution, and the metallurgical effects in the material welded. Special reference is to be made to the problem of resistance welding of heat-treatable steels, of either the medium carbon or of the low-alloy type.*

So far, an analysis of the heat flow in spot welding has been made, and checked by measuring actual weld nugget diameters. The theory enables the "weld time" for the most efficient use of energy to be calculated and the times obtained agree well with those determined by experience and practical test methods. Development of the theory to cover cooling rates is under way, and methods of measuring thermal cycles during welding are being tested, *i.e.* the relationship between the electrical cycle of the welding machine, the energy actually reaching the weld and the thermal cycle in and around it are being determined by both mathematical and experimental methods.

A review of British and American literature on spot welding hardenable steels has been prepared for the Committee.

LR. COMMITTEE—Resistance Welding of Light Alloys

This Committee was set up in 1947 *with the following terms of reference:—"To investigate the resistance welding of light alloys."*

The Committee began its programme with two reviews of information, one on spot welding and the other on flash and butt welding of light alloys, which were published in "Welding Research."

In 1947 a research programme on the spot welding of two aluminium alloys (D.T.D. 610B and D.T.D. 687) was undertaken on behalf of the Ministry of Supply, and the Committee took an active part in this, much useful advice being given on various aspects of the work. The first stages of the work covered the pre-welding surface preparation of the material, and the development of suitable instrumentation for measurement of machine performance (current and load cycles) for condenser-discharge type spot welding machines. Results of this initial work have been published.

Performance characteristics of the welding machines were assessed in detail, and in all this work considerable use was made of statistical techniques, to allow the maximum amount of information to be obtained. Welding tests were made using 14, 16 and 20 s.w.g. material, and involved over 10,000 specimens, containing more than 30,000 welds. Weld quality was assessed by mechanical tests and metallurgical and radiographic examination. Final reports have been prepared for publication.

In addition to the main programme, some structural spot welding was undertaken in conjunction with Percival Aircraft Co. Ltd. with very satisfactory results. The spot-welded components were shown to compare favourably with riveted structures in both static and fatigue strength properties. A report on this work has been prepared for publication.

Preliminary tests on methods of welding light alloys with reduced power demands have been carried out, using material with a thin anodic oxide film or a coating of Al-Si brazing alloy on the faying surfaces only.

Intended future work covers an assessment of the properties of welds made using different current wave forms (e.g. that produced by the 3-phase frequency changer type welding machines), in co-operation with the Ministry of Supply and aircraft companies, and an extension of the work on possible low-power methods of spot welding aluminium and its alloys.

Reports to Members

LR./4/49 TEANBY, P. M.—A Review of Recently Published Information on the Spot Welding of Light Alloys.

LR./6A/50 DIXON, H. E., and GAMESON, J. H.—Machine Characteristics for Flash Welding Aluminium Alloys.

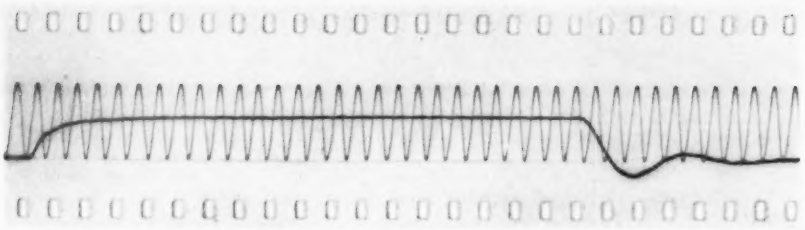
LR./8A/50 DIXON, H. E.—An Account of Tests on the Pre-Welding Surface Preparation of 20, 16 and 14 s.w.g. D.T.D. 610B and D.T.D. 687.

LR./9A/51 DIXON, H. E.—Instrumentation for the Measurement of Secondary Current Electrode Load Cycle, and Electrode Tip Velocity on Condenser Discharge Machines.

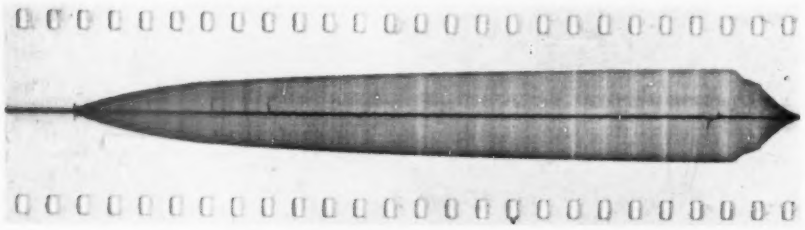
LR./12A/51 DIXON, H. E.—Summary of the Aluminium Alloy Spot Welding Programme.

LR./17/52 DIXON, H. E., and ROBERTS, J. E.—A Double Beam Load Unit for the Static Calibration of Electrode Tip Load in Spot Welding Machines.

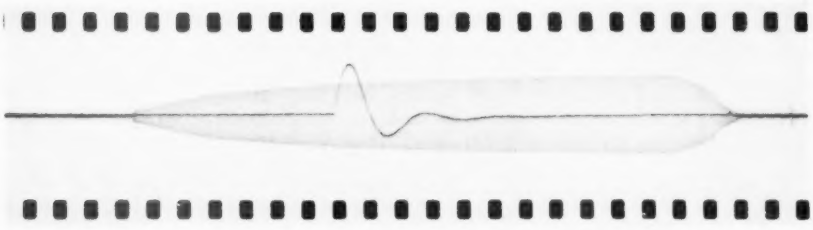
LR./18/52 Summary of a Paper on Optimum Flash Welding Conditions for Aluminium Alloys.



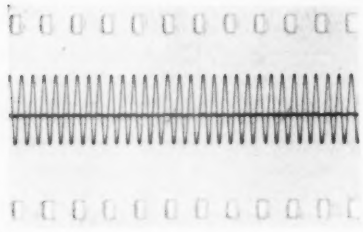
(a) Charging voltage with time trace.



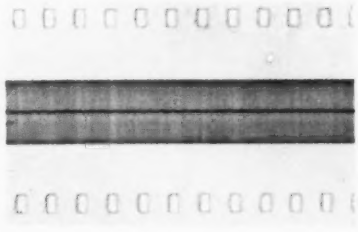
(b) Electrode load cycle.



(c) Electrode load cycle with short circuit secondary current.



(d) Current calibration.



(e) Load calibration.

Measurement of condenser discharge spot welding machine variables by oscillographic recordings.

Published Work

TEANBY, P. M.—"A Review of Selected Papers on the Flash and Butt Welding of Light Alloys."—*Welding Research*, **3** (6), December, 1949.

TEANBY, P. M.—"A Review of Recently Published Information on the Spot Welding of Light Alloys," *Welding Research*, **4** (5), October, 1950.

DIXON, H. E., and GAMESON, J. H.—"Machine Characteristics for Flash Welding Aluminium Alloys," *Welding Research*, **5** (2), April, 1951.

DIXON, H. E.—"Surface Cleaning of Some Aluminium Alloys prior to Spot Welding," *Welding Research*, **6** (5), October, 1952.

DIXON, H. E., ROBERTS, J. E., and ROBERTS, T. M.—"The Measurement of Spot Welding Machine Variables," *Welding Research*, **7** (1), February, 1953.

Techniques and Memoranda

Most of the booklets mentioned on the following list were prepared as a direct result of the work of one or more of the Committees of the Association. These documents give both an authoritative opinion and useful advice on many problems and methods in the welding industry. Further booklets are in course of preparation, including one on Projection Welding of Steel (T.30).

Members of B.W.R.A. can obtain out of print copies on loan. All Members are entitled to two free copies of each T booklet **at the time of issue.**

Title.	*Ref.*	*Price (postage free)*
Gas welding of aluminium. (Published by arrangement with the Aluminium Development Association, Reference No. 5)	*T.*1a	2/-
The arc welding of high tensile (low alloy) structural steels. 2nd Ed., Feb. 1944	*T.*2	9d.
The oxy-acetylene machine cutting of low alloy high tensile structural steels. June 1941	*T.*4	*Out of Print*
Recommendations for oxy-acetylene butt welds in mild steel pressure pipe lines. 3rd Ed., 1946	*T.*5	2/-
Colour Charts for T.5.		*Out of print but to be reprinted*
Technique for the gas welding of copper. Ill. Feb. 1943	*T.*6	2/6
Spot welding of light alloys in aircraft construction. Ill. June 1942 by Sutton, H.	*T.*7	*Out of print*
Memorandum on deep penetration butt welding with semi-automatic welder. Ill. Feb. 1943	*T.*10	Free
Memorandum on deep penetration fillet welding. Ill. May 1943	*T.*11	*Out of Print*
Memorandum of manual welding of butt welds in the downhand position, and with welded-on backing bars	*T.*12	*Out of Print*
Recommended technique for making fillet welds in the downhand, vertical and overhead positions. Ill. Revised March 1945	*T.*13a	Free
The control of welding. Papers contributed to a Symposium organised by the Scottish Branch of the Institute of Welding, Glasgow, 14th March, 1944, Oct. 1944	*T.*14	*Out of Print*
Recommended technique for making butt welds in mild steel plating in the downhand position with overhead back runs and in the vertical and horizontal positions. Ill. Nov. 1945	*T.*15	Free
Technique for the gas welding of magnesium alloys. May 1946	*T.*16	2/-
Arc welded structural steelwork. I. Stanchion bases, caps and joints. March 1946	*T.*17	9d.
Recommendations for the design of arc welded mild steel machinery constructions. 1948 (second printing)	*T.*18	3/6

(continued on next page)

Title	*Ref.*	*Price*
The testing of light alloy fusion welds. 1948	*T*.19	2/-
Heat treatment of welded constructions in mild steel. 2nd Ed., 1950	*T*.20	1/6
Technique for spot welding low carbon steel from 0·022 in. (24 s.w.g.) to $\frac{1}{8}$ in. 2nd Ed. 1953	*T*.21*A*	2/-
Memorandum on faults in arc welds in mild and low alloy steels. 1950 (second printing)	*T*.22	2/6
Recommendations for the metal arc welding of butt welds in steel pipelines for power plant. 1950	*T*.23	2/-
Recommendations for the standardisation of the radiographic examination of welded joints in mild steel pressure vessels	*T*.24	1/6
Photographic aspects of the radiography of welded high pressure vessels by Mullins, L.	*T*.25	2/-
Recommendations for the design and fabrication of arc welded structural steelwork, built-up girders and compression members. 1950	*T*.26	1/6
The Industrial use of flash welding, dealing in particular with ferrous materials. 1951	*T*.27	2/6
Recommended designs for metal arc welded mild steel building structures. Beam and Column Connections. 1952	*T*.28	2/6
Memorandum on non-destructive methods for the examination of welds. 1952	*T*.29	5/-

The Association has also published a book giving a comprehensive survey of "The Welding of Austenitic Corrosion- and Heat-Resisting Steels," 1953. Price 27/6 (*postage* 1*s. extra.*)

A sliding scale calculator has been published giving details of mild steel metal-arc electrodes available in Great Britain 2nd. Ed., 1953. Price 5/- (*postage* 3*d. extra.*)

A list of published reports and other available literature can be obtained on request to Publications Officer, 29, Park Crescent, London, W.1.